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Boston College

The Graduate School of Nursing

COMPUTERIZED LUNG SOUND ANALYSIS

AS AN INDICATOR FOR ENDOTRACHEAL SUCTIONING

IN MECHANICALLY VENTILATED PATIENTS

a dissertation

by

JOSEPH O. SCHMELZ, R.N., M.S.

submitted in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

May 1996

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ABSTRACT

Computerized Lung Sound Analysis as an Indicator of the Need for

Endotracheal Suctioning in Mechanically Ventilated Patients

Joseph O. Schmelz, RN, MS

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The purpose of this study is to extend prior research on the role of

adventitious lung sounds as an accurate indicator of the need for endotracheal

suctioning (ETS) in adult patients requiring mechanical ventilation and

endotracheal intubation. Prior research has demonstrated a link between the

presence of adventitious lung sounds and secretions in the tracheobronchial

tree. However, many questions still remain unanswered in relationship to: lung

sound characteristics, pattern, relationship to the respiratory cycle, volume of

airway secretions, and clinical decision making. The following research

questions were addressed. What is the pattern of adventitious lung sounds

present immediately prior to ETS? How do adventitious lung sounds patterns

change after ETS? What is the relationship between adventitious lung sounds

volume of tracheobronchial secretions aspirated by ETS? 4. What relationship

exists between the degree of importance of rhonchi perceived by the patient's

primary nurse, in the decision to suction, and rhonchi measured by computer

analysis prior to suctioning? Results: Repeated measurements of fifteen

subjects were analyzed. No consistent pattern of lung sounds was identified prior to suctioning. Five adventitious lung sounds were identified: rhonchi, wheezes, crackles, type II rhonchi and coarse sounds. There was a 14 percent reduction in the occurrence of adventitious lung sounds after suctioning. In addition, coarse sounds decreased in duration after suctioning in most patients. There was no relationship between lung sounds and the volume of aspirate obtained. There was also no relationship between the perceived importance of rhonchi and the actual rhonchi recorded. More importantly, the Decision to Suction Now instrument was not predictive of the volume of secretions obtained. It was concluded that the use of sputum volume obtained by blind suctioning is an unreliable measure for predicting the appropriate timing and success of suctioning. Further research using a larger population, multiple sites, acute and chronic settings, suctioning using direct visualization, and localization techniques is necessary.

CHAPTER 1

Introduction

Advances in medical care and technology over the past several decades

have allowed for the development of dramatic life saving measures. Such is the

case in patients who experience episodes of Acute Respiratory Failure (ARF).

The use of endotracheal intubation and mechanical ventilation is required to

assume the "work of breathing" for ARF patients. Since its first widespread use

during the polio epidemic in the early 1950's, mechanical ventilation has become

a commonly used therapeutic modality. In the critical care environment, many

patients require mechanical ventilation as part of their care for respiratory

dysfunction (Rosen & Bone, 1990). For example, the APACHE II study

evaluated the prognosis of critically ill individuals. Of the nearly 4000 patients

entered in this study, forty-nine percent were intubated and placed on

ventilators (Knaus, 1989). Caring for the individual on a ventilator heavily taxes

the health care system both in terms of human and financial resources. Cost of

care for patients who require mechanical ventilation can be four times the cost

for similarly ill ICU patients (Rosen & Bone, 1990).

Although endotracheal intubation and mechanical ventilation are often

necessary life-saving interventions, they can be harmful to the patient. One of

the most common consequences of endotracheal intubation is hindrance of the

patient's normal airway clearance mechanisms. As a result, secretions, mucus,

and debris from the tracheobronchial tree "pool" at or near the tip of the

endotracheal tube. These secretions pose a threat to the patency of the artificial airway (Stone & Turner, 1989). To promote optimal oxygenation and ventilation, endotracheal suctioning (ETS) using mechanical aspiration is performed routinely by nurses to remove secretions on all patients receiving mechanical ventilation. A flexible catheter is passed into and then down the lumen of the endotracheal tube. Secretions are evacuated from the main stem bronchus, lower segment of the trachea, and inner surface of the endotracheal tube using suction.

Endotracheal suctioning is the standard of care for all patients receiving mechanical ventilation. As a result, ETS is the most common respiratory procedure performed by nurses (Nelson, 1992). It may be performed as often as every 15 minutes, on an "as needed" basis, or more commonly, as a routine (e.g. every two hours). As secretions build-up in the upper airways of patients with endotracheal tubes, abnormal or "adventitious" lung sounds are generated. To determine the need for ETS, nurses use chest auscultation to evaluate the presence of adventitious lung sounds (AACN, 1990). Kim & Larson (1987) state that auscultation of breath sounds is the most important physical examination technique for providing an indication of the effectiveness of airway clearance.

Purpose

The purpose of this study is to extend prior research on the role of adventitious lung sounds as an accurate indicator of the need for endotracheal suctioning (ETS) in adult patients requiring mechanical ventilation (MV) and endotracheal intubation. Prior research has demonstrated a link between the presence of adventitious lung sounds and secretions in the tracheobronchial tree (Amborn, 1976; Knipper, 1984; Knipper, Bulechek, Titler, & Alpen, 1991). However, many questions still remain unanswered in relationship to: lung sound characteristics, pattern, relationship to the respiratory cycle, volume and density of airway secretions, and relationship of lung sounds perceived by the nurse.

Specific Aims

The specific aims of this study are to: 1) analyze adventitious lung sounds immediately prior to ETS using new lung sound recording and analysis technology (Time-Expanded Waveform Analysis); 2) quantify the differences in the lung sounds observed before and after ETS; 3) determine the relationship between the change in adventitious lung sounds after suctioning and the volume and weight of secretions aspirated from patients' tracheobronchial tree; and 4) determine the relationship between the importance of rhonchi as perceived by the nurse, in the decision to suction the patient and the quantity of rhonchi actually present prior to suctioning, using Time Expanded Waveform Analysis (TEWA). The research questions that follow, will address these specific aims.

Research Questions

1. What is the pattern (classification, quantity, timing in relation to the respiratory cycle, and location) of adventitious lung sounds present immediately prior to ETS?

2. How do adventitious lung sounds change in quantity, timing in relationship to the respiratory cycle, and location after ETS?

3. What is the relationship between the change in quantity of adventitious lung sounds recorded after suctioning and the volume and weight of tracheobronchial secretions aspirated by ETS?

4. What relationship exists between the degree of importance of rhonchi perceived by the patient's primary nurse, in the decision to suction, as measured by the Decision To Suction Now (DSxN) instrument and the quantity of rhonchi measured by TEWA prior to suctioning?

Definitions (theoretical & operational)

Adventitious lung sounds

Adventitious or abnormal lung sounds are classified as continuous or discontinuous. Continuous sounds usually last more than 0.25 seconds and frequently have a musical quality. Continuous sounds are further divided into rhonchi and wheezes. Discontinuous sounds occur in brief bursts, and are subdivided into coarse and fine crackles (Murphy & Holford, 1980).

Crackles

Crackles are discontinuous adventitious lung sounds, characterized as interrupted explosive sounds, either coarse or fine. Coarse crackles are described as loud and low in pitch, sometimes referred to as coarse rales. Fine crackles are less loud, shorter in duration, and higher in pitch than coarse crackles. These are sometimes referred to as fine rales ("ACCP-ATS Pulmonary Nomenclature," 1975).

Wheezes

Wheezes are continuous adventitious lung sounds, characterized as longer than 250 milliseconds (msec), and high-pitched. The dominant frequency is 400 Hertz (Hz) or more. They are similar to a hissing sound, and are sometimes referred to as sibilant rhonchi ("ACCP-ATS Pulmonary Nomenclature," 1975).

Rhonchi

Rhonchi are continuous adventitious lung sounds, characterized as longer than 250 msec, and low-pitched. The dominant frequency is 200 Hz or less and they are similar to a snoring sound. These are sometimes referred to as sonorous rhonchi ("ACCP-ATS Pulmonary Nomenclature," 1975).

Pattern of adventitious lung sounds

A pattern is a functional integration of elements which together form a unit. For the purposes of this study the pattern of adventitious lung sounds is determined by mapping the occurrence of abnormal lung sounds in relationship

to their: classification, quantity, timing in relation to the respiratory cycle, and location of microphone.

Classification of adventitious lung sounds

Abnormal lung sounds will be classified as either: crackles, rhonchi, or wheezes.

Quantity of Crackles

The number of individual crackles are counted within two complete respiratory cycles (one respiratory cycle is counted as the beginning of one inspiration to the beginning of the next inspiration). For example, subject #1 has 22 crackles in two respiratory cycles.

Quantity of Rhonchi and Wheezes

The duration of a rhonchus or wheeze is divided by the duration of the respiratory cycle in which it is contained. This yields a duration percentage. For example, subject #1 has rhonchi in 15% of inspiration.

Timing in Relation to the Respiratory Cycle

The occurrence of adventitious lung sounds will be identified in relation to inspiratory and expiratory phases of the respiratory cycle. By simultaneously recording sound over the trachea, inspiration and expiration can be identified.

Location of the Microphones

Abnormal lung sounds will be described in relation to the position of the microphone that records the sound. If more than one microphone records an

individual sound, the position will be determined by using the microphone displaying the highest sound intensity.

Time Expanded Waveform Analysis (TEWA)

TEWA is a computer-based method for creating visual displays of lung sounds. The computer employs digital sound recording and time expansion technology to display sounds as waveforms. The time dimension is exaggerated so that sound waves are viewed in increments of approximately 0.14 seconds (a tenth of a second). Prior research has shown distinct waveform morphologies for each adventitious lung sound.

Volume of Secretions

Amount of endotracheal aspirate removed by suctioning, as measured in cubic centimeters (cc) to the nearest 0.1 cc.

Weight of Secretions

Amount of endotracheal aspirate removed by suctioning, as measured in milligrams (mg) to the nearest 0.1 mg.

Viscosity Index

The viscosity index is a calculated ratio of volume and weight (cc/mg) of the aspirated secretions. For example, if the volume of aspirate is 1.2 cc and the weight is 2.5 mg the viscosity index would be 0.48.

Assumptions

1. Endotracheal tubes inhibit the normal clearance of airway secretion.

2. The presence of secretions in the upper airways generates abnormal lung sounds which are transmitted through the chest wall.

3. Microphones applied to the chest wall are capable of collecting and transmitting the lung sounds generated within the thorax to a computer which stores and retrieves the data.

4. The use of endotracheal suctioning in intubated patients is an effective measure for removing sound generating secretions from the upper airways.

5. The patient's primary nurses use a wide range of cues to determine when a patient requires endotracheal suctioning. Nurses' clinical judgments are the best indicator of the need for endotracheal suctioning.

Delimitations

Only adults requiring mechanical ventilation and endotracheal intubation and suctioning will participate in this study.

Limitations

This results of this study can not be generalized due to the sampling methods, sample size and design of this study. Using a convenience sample may influence the results. There was a trend to delay included severely ill patients into the study until their medical condition improved. In addition, the knowledge generated can not be generalized to non-intubated patients, or patients with tracheostomy tubes.

Significance (theoretical & practical)

As mentioned earlier, pervious research has demonstrated a link between adventitious lung sounds and the presence of secretions in the tracheobronchial tree. However, use of lung sounds has been somewhat limited in the past because of confusion over terminology, a lack of understanding of the mechanisms that produce such sounds, and the variability among observers (Knipper, 1986). It is this gap in the current research that this study is intended to address. This research has the potential to improve clinical nursing practice by identifying adventitious lung sounds typical of tracheobronchial secretions. Findings of this study may provide the knowledge base to improve nurses' clinical diagnostic and therapeutic decision making, evaluate efficiency of suctioning techniques, and reduce the incidence of adverse patient outcomes commonly experienced by patients treated with ETS by suctioning only when necessary. Loudon (1993) commented that by better understanding the meaning of sounds that we hear, we can apply the standard simple familiar stethoscope with greater advantage to patient assessment and management. Application of this knowledge has potential not only in the critical care arena but also pulmonary rehabilitation areas and nursing education. In addition, this research will demonstrate that these sounds may be obtained from patients easily, using non-invasive available technology and can be readily quantified, cataloged and stored. Further development of this technology may lead to new

patient monitoring devices, diagnostic aides and new education and training programs.

In 1993, the US House of Representatives Committee on Appropriations encouraged the National Heart, Lung, and Blood Institute (NHLBI) to consider the benefits of enhanced research on effective practices in the critical care arena. The NHLBI convened a task force which identified clinical research in the areas of patient monitoring and mechanical ventilation among its list of 12 important research areas for the future (Lenfant, 1995). This proposed research falls within these two research priorities.

CHAPTER 2

Review of Literature

Introduction

The literature pertinent to the research questions posed by this study can be divided into: lung sound generation, endotracheal suctioning, clinical judgment, lung sounds as indicators of tracheobronchial secretions, reliability of lung sound descriptions, and TEWA technology.

Lung Sound Generation

Breathing causes the tissues, liquids and gases of the respiratory tract to move. Often this movement produces sound. Pulmonary abnormalities (i.e. fluid accumulation) and disease (i.e. pneumonia) can alter the sound produced by the lung. Lung sounds are categorized as normal or adventitious (added). Forgacs (1978) classified adventitious lung sounds as continuous (high-pitched or low-pitched) or discontinuous. High-pitched continuous lung sounds are referred to as wheezes and low-pitched continuous lung sounds are called rhonchi ("ACCP-ATS Pulmonary Nomenclature," 1975). Loudon (1993) comments that rhonchi and wheezes are of sufficient duration that they have a perceivable pitch or "musical" quality.

Rhonchi

Murphy & Holford (1980) noted that rhonchi are sometimes referred to as "coarse breath sounds" because the lower frequencies are accentuated and some of the higher frequencies are lost. They suggest that low-pitched

continuous sounds are often associated with production of sputum (secretions).

The presence of a sputum flap vibrating in the air steam may produce rhonchi

that clear after the patient coughs. Rhonchi can be classified as one of three

types. Type I or classical, is described as relatively uniform, undulating pattern,

longer than 250 milliseconds (msec). Type II also has an undulating pattern,

however it is interrupted intermittently. Type III are short and irregular, exhibiting

a pattern similar to coarse crackles (Hoogendoorn & Murphy, 1990)

Wheezes

Wheezes tend to occur in pulmonary diseases associated with airflow

obstruction such as asthma (Loudon, 1993). Although wheezing is not

diagnostic of asthma, the bronchoconstriction often seen in asthmatics is thought

to obstruct airflow and generate the characteristic high-pitched sound.

Crackles

In contrast, discontinuous (interrupted) lung sounds are referred to as

crackles (rales), due to their crackling or bubbling quality. Crackles can be

subdivided into fine or coarse. As is the case with rhonchi and wheezes,

crackles are usually an indication of an abnormality. The bubbling sounds are

thought to be generated by the presence of copious secretions. As the air

bubbles through the liquids which form a thin film, an explosive sound is

produced (Loudon & Murphy, 1991). Another theory suggests that crackles are

produced when small airways are suddenly opened with rapid equalization of

pressure. Fredberg and Holford (1983) have challenged this theory. Using

mathematical formulas, they suggest that crackles result from sudden changes in elastic stress in the airway walls. This "stress-relaxation quadropole" theory states that the sound spreads in a cloverleaf pattern (Murphy, 1993).

<p style="text-align:center">Endotracheal Suctioning</p>

Although ETS is the standard of care performed by nurses on patients with endotracheal tubes, endotracheal suctioning is a potentially lethal procedure. Numerous researchers have examined the complications associated with endotracheal suctioning including infection (Crane, Tagle, & Palutke, 1981; Cross & Roup, 1981), hypoxemia (Adlkofer & Powaser, 1978; Peterson, Pierson, & Hunter, 1979; Skelley, Deeren, & Powaser, 1980), damage to the endothelial layers of the airways (Kubenski, 1978; Sackner, Landa, Green, & Robinson, 1973), hypotension (Goodnough, 1985), increased intracranial pressure (Bruya, 1981; Parsons & Shogun, 1984); cardiac arrhythmias (Shim, Fine, Fernandez, & Williams, 1969; Mathais, 1976) and death (Marx, Steen, & Arkin, 1968).

In an effort to minimize the complications of suctioning, prior research has focused primarily on suctioning techniques. Variables such as hyperoxygenation (increased inspired oxygen), hyperventilation (increased respiratory rate), hyperinflation (volume of inspired air greater than baseline tidal volume), and the use of adapters to maintain continuous ventilation throughout the suctioning procedure (Stone & Turner, 1989) have been studied in depth.

In addition to improving the procedural aspects of suctioning, researchers have suggested that complications can be reduced by performing the procedure

only when necessary (Knipper, 1986). In order to minimize unnecessary suctioning, evaluation of the usefulness of specific signs and symptoms indicating the need for endotracheal suctioning is indicated. To date there have been only a handful of published research studies evaluating the indications for endotracheal suctioning. As a result, minimal scientific basis has been provided upon which nurses can base their decision to suction (Thompson & Edminston, 1995).

<u>Clinical Judgment: Decision to Suction</u>

As mentioned above, the focus of the nursing literature related to suctioning has centered on risks and procedural aspects. Research evaluating clinical judgment and the indicators of suctioning is only now beginning to emerge in the literature. Thompson, Wiggins, & Sims (1994) examined the frequency and importance of 13 criteria in the nurse's decision to suction. Using a visual analog scale to rate degree of importance, the authors report that the time since last suction, patient request, rhonchi, coughing, and mucus visible in the tube were rated as most important. On average, the nurses used 4.7 criteria to reach a decision to suction the 51 mechanically ventilated post cardiac surgery patients. This suggests that the decision to suction is rarely based on a single criteria, but rather on combinations of the top five. The highest mean rating of importance (scale 0 - 100) was time since last suction (60) followed by patient request (55) and rhonchi (41). The authors report the time since last suction was most frequently two hours. Although there was no policy stating a

routine schedule to suction, this finding supports the conclusions of others that time is often the prevailing criteria used by many nurses.

It should be noted that rhonchi was the only adventitious lung sound listed on the tool used for measurement (although there was a space for "other" criteria not listed). In addition, decreased breath sounds was listed on the tool. However, it was selected as an important criteria only 33% of the time, with an average importance rating of only 19. This study demonstrates that rhonchi are currently used by nurses as an important indicator for suctioning.

Copnell & Fergusson (1995) asked 24 pediatric intensive care nurses, with varying levels of knowledge, open ended questions related to their: theoretical knowledge, ability to apply this knowledge, suctioning practice, and decision making methods in relationship to suctioning. The majority of the nurses (83%) identified more than one of the reasons cited in the literature. They identified seventeen (17) criteria they used for assessing respiratory status. In addition, the nurses listed 20 criteria they used to make the decision to suction. No one single criterion was mentioned by all respondents. Finally, the frequency of suctioning fell within a 1-3 hour time span. Of interest to this study is the interface between the respiratory assessment criteria and the suctioning criteria. Auscultation was the second most frequently reported (80%) respiratory assessment criterion. However, only 3 nurses used auscultation ("audible secretions") in their decision to suction. The respondents favored

technologically-based criteria (e.g. pulmonary artery pressures, oxygen saturation).

<u>Clinical Judgment: Ineffective Airway Clearance</u>

Although not specifically addressing endotracheal suctioning, the literature dealing with the nursing diagnosis, ineffective airway clearance can contribute to our understanding of suctioning indicators. Keep in mind that the basis for suctioning is to remove secretions from the tracheobronchial tree. In order to reach the conclusion that a patient needs ETS, the nurse can apply the diagnostic label: ineffective airway clearance (IAC). IAC is defined as the inability to clear secretions from the respiratory tract to maintain airway patency (NANDA, 1994).

To date, the research around IAC has dealt exclusively with the content validity of the defining characteristics. These studies are useful because the defining characteristics of the nursing diagnosis IAC are used by the nurse to determine whether the diagnosis applies to a particular patient. In other words, the defining characteristics of IAC should be similar to the criteria used in the decision to suction.

<u>Diagnostic Content Validation (DCV) studies</u>

Most research published to date use the Diagnostic Content Validation (DCV) methodology proposed by Fehring (1986, 1987). The DCV methodology calls for expert nurses to rate the importance of each defining characteristic of a given diagnosis. The ratings are converted to weighted scores, summed and

averaged. Fehring (1987) established cut-off scores to categorize characteristics as major (greater than 0.80) or minor (between 0.50-0.80). Recently, Fehring (1994) proposed specific guidelines for determining what constitutes an expert nurse for use in validation studies. Key among these attributes is a Master's degree in Nursing.

NANDA's Defining Characteristics	Defining Characteristics Listed in study	DCV Gordon (1994) N=111	DCV Wake et al (1991) N=51	DCV Brukwitzki et al (1991) N=50	DCV Clark (1994) N=123	CDV Carlson-Catalano (1994)
Abnormal breath sounds [rale(crackles), rhonchi (wheezes)]	Rhonchi(wheezes)	.738	.667	.570		
	Rhonchi(gurgles)			.724		
	Rales(crackles)	.727	.564	.560		
	Abnormal breath sounds			.575	.768	.71
	Decreased breath sounds	.700	.603	.600		
	Absent breath sounds			.670		
Changes in rate or depth of respiration	Changes in rate or depth of respiration	.701	.740		.705	
	Abnormal respiratory pattern			.575		
	Paradoxical breathing pattern/ accessory muscle use				.677	
	Use of accessory muscles	.607				
	Decreased chest expansion				.643	
Tachypnea	Tachypnea		.735	.595	.636	
	Bradypnea			.367		
	Asymmetric chest excursion			.490		
	Abnormal I:E ratio			.465		
	Decreased maximum inspiratory/expiratory pressure				.616	
Cough, effective/ ineffective; with or without sputum	Cough, effective/ ineffective; with or without sputum				.861 *	
	Cough, ineffective		.926 *	.905 *		
	Cough, effective		.309	.310		
	Productive cough	.573				
	Cough					.52
	Sputum, tenacious		.873 *	.790		
	Sputum, copious		.868 *	.750		
	Sputum, increased			.670		
	Sputum, decreased			.347		
	Sputum, change in color			.530		
	Sputum					.57
	Change in quality or quantity of mucus				.783	
Cyanosis	Cyanosis		.799 *	.564		
	Cyanosis of lips/nailbeds	.577				
	Cyanosis of mucous membranes	.538				
Dyspnea	Dyspnea		.891 *		.711	
	Reports SOB	.673				
	Air hunger			.597		
	Dyspnea on exertion	.657		.460		
	Dyspnea at rest	.621		.535		

Figure 1. Summary of Content Validity Studies: Ineffective Airway Clearance

Note. ☐ = >.700   shaded & * = >.800 (Major Characteristic: NANDA)

Wake, Fehring, & Fadden (1991) used the DCV model to measure defining characteristics of three nursing diagnoses: anxiety, hopelessness, and IAC. Although this was a multinational study, a sample of 51 American nurses was included. For the purposes of this discussion, only the data from the USA subgroup will be used due to the unknown impact of language, cultural, expertise, and scope of practice issues of the nurses from other countries. Although only six percent of the USA nurses had a Master's degree, it appears reasonable to classify them as experts in IAC based on their level of experience (average years in nursing: 8.4; years in ICU: 5.9) and familiarity with nursing diagnosis (self rated knowledge of nursing diagnosis: 3.96, 5 = high).

The defining characteristics used in this study were drawn from NANDA's Taxonomy I and additions and deletions made by a nurse expert in each diagnosis. Revising the original list of defining characteristics is a common practice in all the DCV studies to date. For example, changes in rate or depth of respiration is one of the defining characteristics listed by NANDA. However the defining characteristics used in the research studies include: changes in rate or depth of respiration, abnormal respiratory pattern, paradoxical breathing pattern, use of accessory muscles, and decreased chest expansion. As a result, it is difficult to make comparisons across studies and draw conclusions. It is possible to infer that the list of defining characteristics is either incomplete or not applicable in every situation.

Ineffective cough, dyspnea, tenacious secretions, copious secretions, and cyanosis were rated as major defining characteristics (>0.80). The defining characteristics related to lung sounds achieved only a modest rating (see Figure 1).

Brukwitzki, Holmgren, & Maibusch (1991) used the DCV model in a three round Delphi survey to validate the defining characteristics of IAC. The study sampled 546 nurses from membership lists of the American Thoracic Society (ATS), AACN, American Lung Association of the Wisconsin Nursing Assembly, or published authors in the area of IAC. Thirty four per cent (N=183) responded in the first round of surveys. Of these, forty five percent (N=88) replied in the second round, and fifty seven percent (N=50) in the third round. The respondents were staff nurses or clinical specialists employed in a respiratory ICU or respiratory outpatient service in an acute care facility. Respondents to the survey were asked to rate 29 defining characteristics of IAC. The syntax was unchanged from that listed by NANDA for only two of the characteristics (tachypnea and cyanosis). The remainder of the defining characteristics listed by NANDA were either reworded or subdivided into more specific phrases. Finally, ten characteristics not listed by NANDA were also included. Only one characteristic, ineffective cough, was rated as a major defining characteristic. Rhonchi were rated higher by this group (0.724), narrowly missing inclusion as a major defining characteristic.

Clark (1994) surveyed 123 master's prepared clinical nurse specialists and staff nurses (non MSN's). Effective/ineffective cough, with or without sputum was rated (.861) as a major defining characteristic. The only defining characteristic related to lung sounds, "abnormal breath sounds" was rated high (0.768).

The survey method was used in a fourth study (Gordon, 1989) of expert nurses' ratings of the defining characteristics of 44 nursing diagnoses identified as high-frequency (Gordon & Hiltunen, 1995) in critical care. From the data of this larger, nation-wide study, a subsample of 111 masters prepared nurses rated the defining characteristics of IAC. All of the seventeen defining characteristics used in this study were rated as minor (between 0.50 and 0.80). Of particular interest is the characteristic "Requires Frequent Suctioning" used in this study. Although rated the highest (0.777), it was not rated high enough to be classified as a major characteristic. Suctioning is an intervention designed to remove secretions from patients' airways in place of normal airway clearance. Thus, suctioning denotes that the judgment of IAC has already been made by the nurse, yet it was not selected as a major defining characteristic by this group of expert clinical nurses.

Clinical Diagnostic Validity (CDV) Studies:

Another of the models proposed by Fehring (1986) to validate nursing

diagnoses is the clinical diagnostic validity model (CDV). This model uses

expert clinical nurses to observe individuals with an established diagnosis. The

experts report the frequency of the defining characteristics as they actually

occur. Carlson-Catalano, Lunney, Paradiso, Bruno, Krynyak-Luise, Martin,

Massoni, & Pachter (1994) used this methodology to identify seven minor

defining characteristics of ineffective airway clearance (see Figure 1). Much like

Clark's (1994) study, abnormal breath sounds were rated high (0.71).

Studies Not Using Fehring's Models:

York (1985) attempted to validate the defining characteristics of IAC and

Ineffective Breathing Patterns using questionnaire, interview, and retrospective

record review. Unfortunately, when asked about the appropriateness of the

defining characteristics in the NANDA definition, the ten expert nurses that

completed the questionnaire did not voice their opinion but rather commented

that the etiologies and defining characteristics were appropriate because they

were identified by NANDA. However, the written comments indicated that the

nurses thought that cough is a defining characteristic of ineffective airway

clearance and would not contribute to a diagnosis of ineffective breathing

patterns. The researcher identified 11 nursing care plans for patients with the

diagnosis of ineffective airway clearance. Subsequently, the clinical records

were reviewed to establish the presence of defining characteristics. Cough and

sputum were present in all 11 of the clinical records. Dyspnea/SOB, tachypnea, abnormal or decreased breath sounds, and rhonchi/wheezes were present in 91% (10) of the clinical records. Due to its very small sample size the results of this study should be approached with caution. In addition, Norris (1989) states that retrospective data from medical records is vulnerable to omissions and errors in recording since there is no way to assure appropriate training and consistency in data entry after the fact.

In a similar study, Capuano, Hitchings & Johnson (1990) asked 100 medical-surgical nurses to determine if the defining characteristics listed by NANDA were appropriate or not appropriate. The assumption made by the researchers was that the nurses cared for patient populations with a "propensity for respiratory problems". Although experienced nurses, it is questionable whether this population can be considered experts. Results for this study showed that all the defining characteristics were associated with the diagnosis more than 67% of the time.

Characteristics associated with diagnosis include: cough, 95%; change in depth respiration, 88%; change in rate respiration, 88%; abnormal breath sounds, 87%; dyspnea, 85%; cyanosis, 76%; and tachypnea, 67%; In addition change in depth of respiration, tachypnea, cough, dyspnea, and cyanosis were identified as overlapping with the nursing diagnosis ineffective breathing pattern.

Summary of IAC Studies

The findings of the various studies are difficult to summarize. However, it is possible to make some conclusions concerning the content validity of ineffective airway clearance. Of particular interest to this discussion are the major defining characteristics of the diagnosis. According to Fehring (1986), ratings above 0.800 are considered major defining characteristics (boxed, shaded & * in Figure 1). However, ratings this high rarely occurred in all studies and it was helpful to use 0.700 (boxed in Figure 1) as a cut-off for interpreting the information particularly in relationship to lung sounds. The data from these studies appears to cluster around four characteristics: ineffective cough, the presence of tenacious, copious sputum, adventitious lung sounds, and patient descriptions of inability to clear secretions from airways. These four characteristics are similar to the NANDA list.

It can be concluded that abnormal lung sounds is a frequently cited criterion used by nurses to make the diagnosis of ineffective airway clearance. Unfortunately, most of the DCV studies were not specific as to which adventitious sound was used by clinicians. Further investigation is needed to determine if specific adventitious lung sounds (e.g. rhonchi) are indicators of Ineffective Airway Clearance.

Adventitious Lung Sounds as Indicators

The presence and movement of fluid in the airways of the lung plays a role in the generation of rhonchi and crackles. For this reason, they are of particular interest as indicators of the need for ETS.

Rhonchi

Amborn (1976) used coarse lung sounds as a variable in her study of clinical signs associated with tracheobronchial secretions. She discovered that these coarse breath sounds were associated with significant amounts (less than half a cc) of secretions aspirated by ETS. Her research may have been the earliest published nursing study measuring clinical signs associated with tracheobronchial secretions. She studied 35 mechanically ventilated adults with either endotracheal or tracheotomy tubes. She hypothesized that the amount of tracheobronchial secretion was associated with the presence of 22 specific clinical signs. In addition, she postulated that the amount of tracheobronchial secretion removed during endotracheal suctioning would assist in identifying predominating signs. Unfortunately, this study preceded the American Thoracic Society's classification system of lung sounds. Instead, the researcher chose to use the term "coarse" lung sounds as the only specific adventitious lung sound. As a result, the exact lung sound or sound measured by this study remains unknown. It is possible that this study was measuring rhonchi which have been described as "coarse" in quality.

A convenience sample of patients from three intensive care units at two separate hospitals was used in this study. A review of extraneous variables for each subject demonstrated a homogeneous mix based on age, sex, present diseases, hemoglobin, medications, fractional inspired oxygen concentration, initial activity level. The author found no association between any one or any combination of these extraneous variables and clinical signs.

The clinical signs of particular interest from this study are: respiratory rate (increased or decreased), pharyngeal gurgle, coarse breath sounds, local absence of breath sounds, and prolonged expiratory breath sounds. The initial results showed that pharyngeal gurgle and local absence of breath sounds were of no value in predicting secretions because they occurred in only four of the 35 patients. These signs were excluded from statistical analysis by the researcher. However, by using the number of times these signs were present as a rationale for exclusion may not have been appropriate. In this case, the author may not have recognized the impact of the variables' effect size. Although these signs did not occur often, they may still be powerful indicators of the accumulation of tracheobronchial secretions. Theoretically, the presence of a pharyngeal gurgle reflects air moving across a large amount of liquid. Therefore, pharyngeal gurgle exerts a large effect size, independent of its occurrence. Another possible reason for the low occurrence rate of pharyngeal gurgle and local absence of breath sounds can be attributed to the research protocol. The data

were gathered 50 minutes after an initial suctioning episode. This time-span may not have allowed enough time for some clinical signs to develop.

Using t-test and Fisher's exact probability chi square statistics, the author reports that the number of clinical signs per subject was associated with the amount of secretions. In particular, six or more clinical signs were exhibited in 90 percent of those subjects having 0.5 cc. or more secretions, in 75% of those subjects with 0.1 to 0.4 cc secretions and in only 25% of those subjects without secretions. An arbitrary cut point for determining a significant amount of secretions was established at 0.5 cc's. Using this cut point, the sample of patients could be evenly arranged into three groups: greater than 0.5 cc secretions, less than 0.5 cc secretions, and no secretions. Although the cut point was useful in establishing statistical significance, the clinical significance of half a cc is questionable.

Amborn's study represents an initial attempt to quantify the relationship between the accumulation of secretions in the tracheobronchial tree and clinical signs. In a related study, Knipper, Bulechek, Titler, & Alpen, (1991) concluded that the presence of coarse breath sounds (again inferring the term rhonchi) over the large airways resulted in a significant amount of aspirate return (>0.5 cc) and was an accurate indicator of the need for tracheal suctioning ($p<.0001$). Both studies, measured adventitious lung sounds by listening with an acoustical stethoscope. Although a common practice in the clinical setting, this method of data collection has questionable reliability. In particular, this method relies on

human auditory perception and variability among individual observers can be great. In addition, the stethoscope provides no direct documentation of data. Problems such as these have lead to difficulties in description of lung sounds. As a result, a plethora of terms for the same sound and two distinctly different sounds being called the same have lead to confusion in describing lung sounds. In contrast, Time Expanded Waveform Analysis allows lungs sounds to be studied objectively, minimizing reliability problems and enabling distinctions between different adventitious lung sounds.

TEWA technology has been used in only one study of adventitious lung sounds prior to ETS. Studying eight patients with artificial airways, Hoogendoorn & Murphy (1990) recorded adventitious lung sounds at five sites simultaneously. They discovered most sounds in these patients were classified as rhonchi. The sounds were relatively continuous, low pitched sounds having a uniform waveform that was labeled type I rhonchi. In addition, these authors report low pitched sounds with irregular waveforms on TEWA that were labeled type II rhonchi. Prior to suctioning they recorded Type I rhonchi at a total of 19 sites during inspiration and 17 sites during expiration. Type II rhonchi were present at 19 sites during inspiration and 27 sites on expiration. Crackles were recorded at only one site during expiration. After suctioning, Type I decreased by 70%, Type II by 55%, and there was no change in number of sites positive for crackles. This study demonstrates a relationship between the presence of

rhonchi and tracheobroncial secretions, although no endpoint was utilized to validate the aspirate.

<u>Crackles</u>

Knipper (1984) evaluated the reliability of auscultating crackles in the upper airways of 26 mechanically ventilated adults with an endotracheal or tracheostomy tube as an indicator of the need for tracheal suctioning. Seventy-seven percent (77%) of the subjects who had crackles produced greater than 0.5 cc. of secretions with suctioning. If crackles were not present, suctioning yielded more than 0.5 cc of secretions in seventy-five percent (75%) of the subjects. When data from patients with existing pulmonary disease were analyzed separately the results were similar for both groups. Eighty-three percent (83%) of the non-pulmonary disease patients who had crackles produced more than 0.5 cc. of secretions. In the absence of crackles, these subjects produced more than 0.5 cc. of secretions one hundred percent (100%) of the time. The effectiveness of the chest assessment protocol for suctioning (suctioning only when crackles were auscultated) was statistically significant compared to suctioning every two hours.

Limitations: It appears that much of this study is based on Amborn's work. As a result, many of the limitations of that study also apply to this one. The suctioning protocol limiting only two passes of the suction catheter is problematic. Suctioning until little or no sputum is aspirated may be better when

the volume of sputum is an outcome measure. The reliability of auscultation as a measurement should also be questioned.

Knipper (1984) discovered an association between crackles (rales) and tracheal secretions. She concluded that crackles heard over the upper airways of the lung indicate the presence of tracheobronchial secretions. However, the presence of crackles prior to endotracheal suctioning is not supported by the research conducted by Hoogendoorn & Murphy (1990). The discrepancy may reflect the method of lung sound measurement. Acoustic stethoscope measurement is subjective and unreliable. It is conceivable that Knipper was hearing Type II rhonchi or a sound similar in acoustic properties to crackles. However, without an objective, reproducible method to measure lung sounds, it is impossible to determine. In this study, as with previous works reviewed, an arbitrary cutoff point for the volume of tracheobronchial aspirate (0.5 cc) was used to show statistical significance. As mentioned earlier, half a cc of secretions in an adult's tracheobronchial tree appears to be too small to be clinically significant. Although the exact amount of sputum considered clinically significant is not cited in the literature nor is it known.

Reliability of Lung Sound Descriptions

The current practice of auscultating lung sounds using a stethoscope is plagued with problems of reliability of observations. Many of the reliability or reproducibility problems are related to errors in terminology and observer variability. During the mid-1970's, an Ad Hoc Subcommittee on Pulmonary Nomenclature was established by the American College of Chest Physicians (ACCP) and the American Thoracic Society (ATS) to discuss the problem of numerous, nonstandard, and often confusing lung sounds terms used throughout the medical literature. Included in the ACCP-ATS nomenclature are the abnormal lung sound labels: coarse crackle, fine crackle, wheeze and rhonchus.

Problems with nonstandard use of terms used to describe lung sounds is not limited to any one profession. In 1979, Bunim and Loudon published an analysis of the terms used to describe crackles (rales). They found 242 case reports published in seven medical journals used the term rale. In these case reports, rale was described using one of sixteen different descriptors. In a similar study, Wilkins, Dexter, & Smith (1984) analyzed 590 case reports from eight medical journals, including the same seven publications that were reviewed by Bunim & Loudon. Seven years after the ATS published its standardized nomenclature, there was little change. For example, the term 'crackles' appeared in only 13.7% of the reports in which one or more adventitious sounds were mentioned.

Gordon (1994) states that diagnostic nomenclature enables nurses to use words consistently. The ATS nomenclature of lung sounds was developed to reduce communication errors made by clinicians when discussing and describing lung sounds. However, even international nursing organizations such as the North American Nursing Diagnosis Association (NANDA, 1994) continue to incorrectly cite the ATS nomenclature. For example, the NANDA list of defining characteristics of ineffective airway clearance includes rhonchi (wheezes). To be unambiguous, the terms should be cited as rhonchi and wheezes.

Observer variability is another source of inconsistency. A serious problem in recalling lung sounds auscultated by clinicians is that, so much information exists (e.g., intensity of the sound, presence or absence of each adventitious lung sound and their relationship to the respiratory cycle, and the ratio of inspiration to expiration). This immense amount of information is extremely difficult to record or to remember (Murphy, 1985a). Historically, Laennec first developed a crude stethoscope in the early 19th century. He used this new device to describe normal and abnormal lung sounds, commenting at the time that lung sounds were easier to recognize than describe (Loudon, 1985).

Murphy (1985a) reviewed the issue of observer variability in relation to lung sounds, referring to numerous research studies (Hudson, Conn, Matsubara, & Pribble, 1978; Schilling, Hughes, & Dingwal-Fordyce, 1955, Fletcher, 1952;

Smyllie, Blendis, & Armitage, 1965; Koran, 1975) which demonstrate observer

disagreement as high as 25%. Murphy comments that the observer variability

can be attributed to the difficulties inherent in verbalizing the subtleties of lung

sound differences. He warns that 'such lack of reliability in findings appears

unacceptable for diagnostic and therapeutic decisions.'

Of particular interest is the reliability in identifying rhonchi which are

commonly heard in patients with airway secretions. In similar studies, Wilkins,

Dexter, Smith, & Marshak (1989) and Wilkins, Dexter, Murphy, & DelBono

(1990) asked respiratory care practitioners to classify examples of recorded

adventitious lung sounds. Both studies found the providers incorrectly used the

term rhonchi to describe both continuous and discontinuous lung sounds.

With the problems inherit in lung sound descriptions, scientists are

continuing to search for ways to improve reliability. Most of the efforts to date

have included recording lung sounds and analyzing the variables of the signal

using computers.

TEWA Technology

The advent of modern technology, in particular advances in acoustical

knowledge and computer science, have provided the tools to allow the

information contained in the acoustical signal from the lung to be "captured",

studied, and transformed into clinically useful data. Employing digital sound

recording and expanding the time axis, Time-Expanded Waveform Analysis

(TEWA) is a computer-based method for creating visual displays of lung sounds.

TEWA provides an objective tool that shows distinctive patterns of the common lung sounds and allows them to be distinguished visually rather than only by ear. (Murphy, Holford, & Knowler, 1977).

When adventitious lung sounds are represented visually as a time amplitude plot by TEWA, their morphology is unique. The waveforms of crackles consist of discrete spikes. The waveforms of wheezes or rhonchi represent something more closely approximating a sine wave (a quasi-periodic signal). Since wheezes and rhonchi have similar waveform patterns on time expanded analysis it is useful to analyze the frequency content of the sound signal. The Fast Fourier Transform (FFT) is capable of rapidly analyzing the frequency content of continuous sounds such as the sine wave. FFT demonstrates the different frequencies contained in a sound signal. The spectral analyses of sound segments are graphed, the frequency content, intensity, and timing in seconds of different pitch can be determined (Loudon, 1993).

TEWA was useful in characterizing the crackles (rales) of asbestos workers and training and validating technicians in detection of these crackles for surveillance of workers (Workum, Del Bono, Holford, & Murphy, 1986). Time-expanded waveform analysis was also used to clarify lung sound nomenclature. Tape recordings of sounds provided by investigators from various parts of the world were analyzed by this method to demonstrate that various terms were used to describe equivalent phenomena (Cugall, 1978). The method was also used to distinguish fine from coarse crackles objectively (Holford, Murphy, Del

Bono, & Workum, 1978; Holford, 1980) and to show that coarse crackles were more widely distributed over the chest wall than fine crackles (Kunica, 1980). It was a key tool in developing and testing the validity of the stress relaxation quadrupole theory of crackle generation (Fredberg & Holford, 1983). This theory is currently the most widely accepted one for the mechanism of production of crackles.

TEWA has been used to characterize the unusual sounds observed in cocaine freebasers (Del Bono, O'Brien, & Murphy, 1989) and to demonstrate auscultatory differences which exist in interstitial pulmonary fibrosis, chronic obstructive pulmonary disease, congestive heart failure, and pneumonia (Bettencourt, Del Bono, Spiegelman, Hertzmark, & Murphy, 1994).

Summary

The review of the literature demonstrates a link between adventitious lung sounds, the accumulation of secretions in the tracheobronchial tree, and the need to suction. However, the clinical relevance of the studies to date is questionable since many used very small amounts of mucus as cutoffs to determine statistical significance. The literature has not reported the type of lung sound or when it can be heard, and where it can be heard still remains unclear. In order to strengthen our understanding of adventitious lung sounds and their relationship to clinical judgment and suctioning, a more objective, reproducible method of lung sound analysis is needed.

CHAPTER 3

Methods

Introduction

This study was designed to describe the role of adventitious lung sounds as a clinical indicator of the need for endotracheal suctioning. In an attempt to understand this dynamic process, four specific aims were identified. They were: 1) to analyze adventitious lung sounds immediately prior to suctioning; 2) to quantify the differences in lung sounds before and after ETS; 3) determine the relationship between adventitious lung sounds and the weight and volume of aspirate; and 4) determine the relationship between the importance of rhonchi perceived by the nurse and the quantity of rhonchi actually present. This chapter will describe the research design and outline the procedures used to collect information in a reliable and valid form to address the aims of the study.

Research Design and Methods

This is a descriptive correlational study. The review of the literature has revealed several variables which are related to the accumulation of secretions in the upper airways. This study measured two main categories: 1) adventitious lung sounds and 2) the nurses' clinical judgment. In order to analyze the adventitious lung sounds associated with secretions in the tracheobronchial tree, lung sounds were recorded in patients requiring mechanical ventilation and endotracheal intubation. Clinical judgment was measured using the Decision to

Suction Now (DSxN) instrument to determine the importance of lung sounds as

an indicator for suctioning.

Research Questions

1. What is the pattern (classification, quantity, timing in relation to the

    respiratory cycle, and location) of adventitious lung sounds present

    immediately prior to ETS?

2. How do adventitious lung sounds change in quantity, timing in relationship to

    the respiratory cycle, and location after ETS?

3. What is the relationship between the change in quantity of adventitious

    lung sounds recorded after suctioning and the volume and weight of

    tracheobronchial secretions aspirated by ETS?

4. What relationship exists between the degree of importance of rhonchi

perceived by

    the patient's primary nurse, in the decision to suction, as measured by the

    Decision To Suction Now (DSxN) instrument and the quantity of rhonchi

    measured by TEWA prior to suctioning?

Setting and Sample

A convenience sample consisting of 15 adult subjects intubated with an

endotracheal tube and ventilated with a volume-cycled ventilator was used. The

subjects were sampled from two critical care units at a metropolitan teaching

hospital.

Subject Eligibility

Criteria for Sample Inclusion:

Ventilator Patient

1. Over 18 years old (age).

2. Requiring volume mechanical ventilator (ventilator capable of delivering manual breaths at 135% of tidal volume and 100% oxygen).

3. Endotracheal tube.

4. Producing tracheobronchial secretions requiring endotracheal suctioning.

5. Respiratory rate greater than 12 breaths per minute.

Primary Nurse

1. One year current experience in critical care nursing.

2. One year current experience in endotracheal suctioning of ventilator-dependent patients.

3. Assigned primary responsibility for ventilator patient listed above.

Criteria for Sample Exclusion:

Ventilator Patient

None.

Primary Nurse

None.

Instruments:

Multi-Channel Lung Sound Analyzer

The investigator used instrumentation which amplifies, filters, and multiplexes the patients lung sounds to a high-speed analog-to-digital converter (ADC) for storage in computer random-access memory (RAM). This Multi-Channel Lung Sound Analyzer (MCLSA) contains a custom designed audio printer circuit board and a Metrabyte DASH© 20 analog-to-digital (A-D) converter board. Each audio channel consists of a 4 pole high-pass and low-pass filter at 80 and 2,000 Hz respectively and a wide band amplifier with gain variable from 1 to 30. A headphone jack and built in speaker permit monitoring the actual lung sounds. Each channel has an external preamplifier (gain = 50) for low noise amplification of the microphone signals. The microphones consist of miniature electret microphones (Radio Shack© product no. 33-1063) mounted to Littman© (3M) Master Cardiology stethoscope chest piece. A high performance 80486 based computer processes the lung sound data and stores it on a Bernoulli© Multidisk drive. The computer stores the digitized lung sounds and displays the sound waveforms on a color monitor for analysis. The entire MCLSA unit is mounted on a small utility cart for convenient use in patient rooms.

Testing and Reliability of MCLSA:

The quality of the performance of the MCLSA was evaluated in three ways: by calibration, waveform inspection and simultaneous listening. An extensive calibration of the MCLSA was performed periodically during the study. The frequency response of the system was tested using audiometery equipment and a sound proof booth. Single frequency sounds of 100, 250, 500, 750 and 1000 Hz were recorded to determine the reliability of the MCLSA's frequency mode. The system was accurate within $\pm$ 2 percent. The accuracy of the MCLSA time mode was measured by placing the microphones 34 centimeters from a sound source. Since the speed of sound is 34 centimeters per second, the transit time should equal one second. Results of this test were accurate within $\pm$ 5 percent.

A shortened calibration of the MCLSA was performed prior to each lung sound recording. A 1000 Hz generator was placed over the microphones, a 10 second recording was made, and the recording was viewed on the computer screen. The waveforms produced by the 1000 Hz generator are measured on the computer screen in the time domain. Waveform length between 0.9 - 1.1 milliseconds (1000 Hz = 1.0 msec/cycle) was necessary to continue data collection.

Inspection of the lung sound waveforms displayed on the computer monitor following each data collection, insured that quality data is being obtained. Problems such as a saturated signal or no signal at all are

immediately identified and corrected. In addition, the sounds being recorded by the MCLSA were simultaneously listened to via audio headphones.

Decision to Suction Now Instrument:

The patient's primary nurse completed the Decision To Suction Now Instrument immediately following each suctioning episode. The DSxN asks the nurse to rate the importance of 13 criteria used in the decision to suction the patient now. Each criterion is rated between "Not at all" to "Most" on a 100 mm visual analog scale (VAS). In addition, this tool has a fill in the blank space which allows the subject to report any additional criterion. This tool appears well suited for the high-tech, time-sensitive critical care environment. The VAS format can be filled out rapidly, allowing the primary nurse to quickly return to the patient care priorities. Of particular interest to this study, the DSxN asks the nurse to rate the importance of rhonchi and decreased breath sounds. The DSxN showed a reliability of 0.96 in a study of decision making in 51 mechanically ventilated patients (Thompson, Wiggins, & Sims, 1994b).

The author reports the content validity of the criterion has been established by expert panels reported by others. A convenience sample of 227 critical care nurses returned a questionnaire (50% response rate) on which three clinical scenarios were described. Each criterion was present in two scenarios but absent in one scenario; each scenario had some suction criteria absent. For each scenario the nurse rated how important each of the 13 decision would be to their decision to suction by placing an X on a 100 mm horizontal VAS.

Convergent validity was established between scenarios where the criteria were present (moderate correlation, $p \leq 0.001$) for all of the criteria. Discriminant validity was established for the criteria of coughing, increased work of breathing, rhonchi, decreased breath sounds, and pulse oximetry for all scenarios; but established for increased work of breathing, peak inspiratory, and patient request in only some of the scenarios. (Thompson & Edmiston, 1995).

Procedures

Procedure for Sample Selection

The investigator communicated with the critical care nurses and respiratory therapists daily to identify patients who met the study criteria. The patient's primary physician was contacted for permission to include the patient in the study. After permission was received from the physician, the patients and next-of-kin were asked for consent.

Procedures for Data Collection

After consent was obtained from the patient and/or next-of-kin, the primary nurse was contacted to initiate the data collection period. The nurse was informed that the patient was enrolled in the study and that lung sounds would be recorded immediately prior to the next suctioning episode based on the clinical judgment of the nurse.. The nurse was responsible for paging the investigator when it was determined that suctioning was required.

The investigator and a research assistant trained in computerized lung sound analysis were located in an office in close proximity to the critical care

units. Once notified, the MCLSA was wheeled to the patient's bedside, plugged in and turned on. The research assistant was responsible for "booting" the computer, turning on the component parts of the MCLSA and performing a bedside calibration of the system. If any adjustments were necessary, the calibration was repeated.

The investigator simultaneously positioned the subject in a 30 degree head up, supine position. Any clothing over the microphone locations was removed. Six stethoscope chestpieces containing the recording microphones, intended to record lung sounds, are applied to the patient's thorax with a 3M© self-adhesive tape. The chestpieces are applied to the following locations: (1) right anterior chest, midclavicular line (RMCL), third intercostal space; (2) right axilla, mid axillary line, fifth intercostal space (RMAL); (3) right interscapular area, paravertebral line at the level of the sixth thoracic vertebrate (T6), (RISA); (4) left anterior chest, mid-clavicular line, third intercoastal space (LMCL); (5) left axilla, mid-axillary line, fifth intercostal space (LMAL); and (6) left interscapular area, paravertebral line at T6, (LISA). A seventh chestpiece/microphone is positioned at the sternal notch (TR) on the anterior chest to simultaneously record sounds in the trachea. Tracheal sound is an accurate indicator of the respiratory cycle. Prior research has used a position anterior to the sternocleidomastoid muscle, right of midline to simultaneously record the respiratory cycle in subjects not on ventilators. However, the subjects in this study have endotracheal tubes which bypass this anatomical position. Tracheal

sounds in intubated patients are best heard at the sternal notch. Tracheal

sound recording allows for measurement of the length of inspiration and

expiration, as well as to help in identifying the respiratory phases during data

analysis.
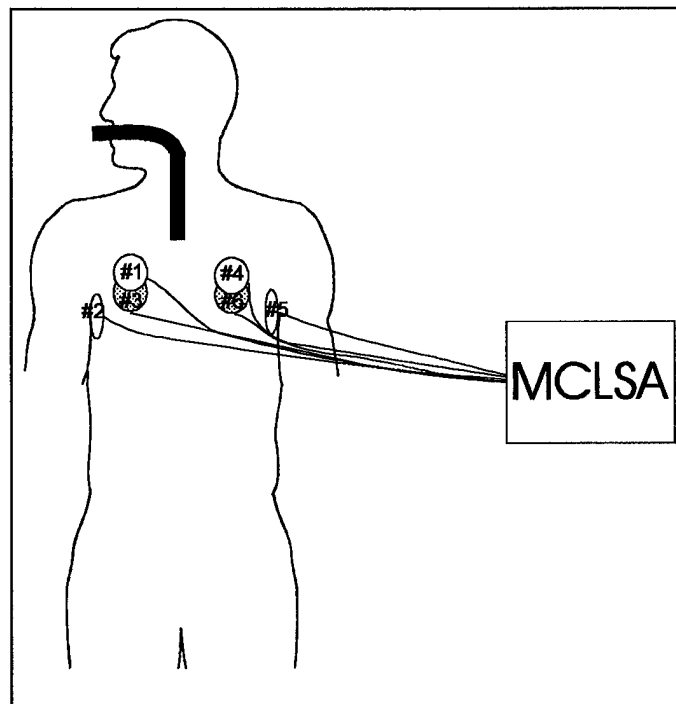
Figure 2: Microphone locations on anterior chest.

Note. shaded locations depict posterior placement.

After applying the chestpieces, the suctioning apparatus was prepared.

The suction was set at 100 mm Hg and 10 cc's of normal saline was injected

through the flush port while suction was applied to clear any residual sputum

from previous suctioning episodes. In addition, all residual normal saline flush

was suctioned from the system. A sputum trap was then attached between the

suction catheter and suction tubing. Finally, the ventilator tubing was checked

for accumulated fluids. If present, these fluids were removed to prevent extraneous sound generation.

Lung sounds were recorded for ten (10) seconds at a sampling rate of 8,000 Hz for the seven microphones. The ten second recording was sufficient to capture at least two complete respiratory cycles per examination. All lung sound recordings were started at the end of expiration as observed by the investigator using chest movement as an indicator. The computer's graphic display of lung sound waveforms was observed to ensure that a satisfactory recording was made over at least two (2) successive breaths.

The patient was then suctioned by the investigator using the protocol described below. Two minutes after the suctioning protocol was completed, a second computerized lung sound recording was obtained. The lung sound waveforms were observed following the same procedure described above. The recording microphones were removed and the primary nurse was asked to complete the DSxN.

Identification of need ==> Apply microphones ==> Calibration & ==>
to suction by RN   to thorax   adjustments

       Record lung sounds ==>   ETS per ==>   RN   ==>
       & evaluate adequacy   protocol   completes
       of data   DSxN tool

          Record lung ==>   Evaluate ==>   Remove microphones
          sounds 2 min.   adequacy of
          after suctioning   data
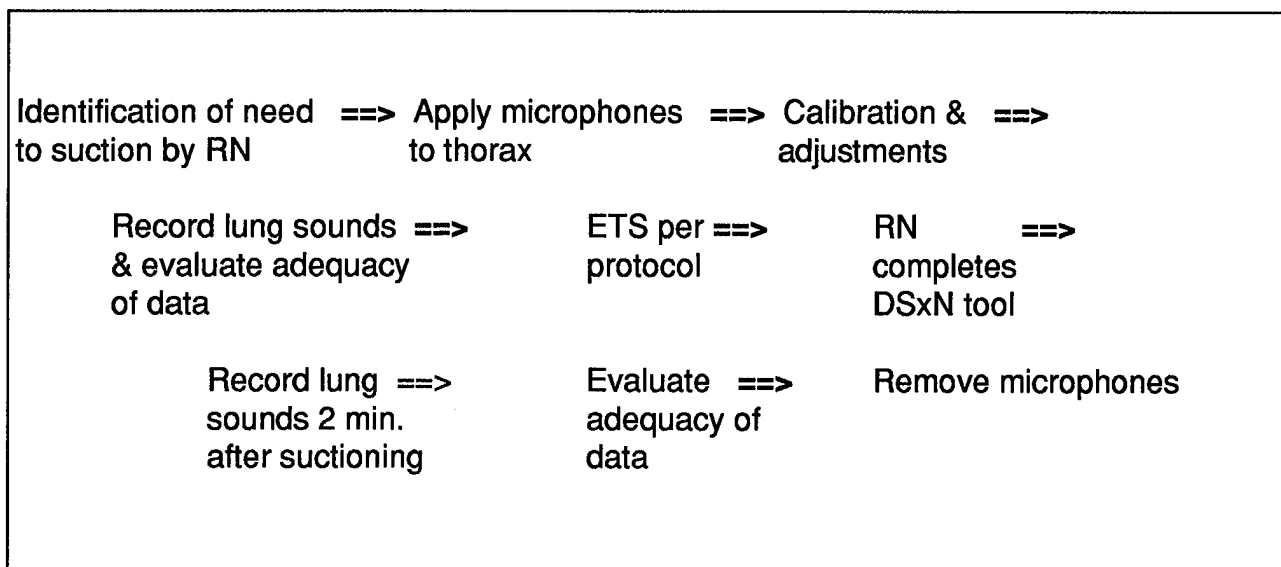
<u>Figure 3</u>. Research protocol outline.

<u>Procedure for Suctioning</u>

With each suctioning event, the patient received five breaths

(hyperventilation) at 135% of tidal volume (hyperinflation) and a fraction of

inspired oxygen (FiO_2) of 1.0 (hyperoxygenation). A directional-tipped 14

French closed system suction catheter was used in all the suctioning episodes.

The directional-tipped catheter has an angled end that allows the user to direct

the catheter toward a particular lung. The first suctioning pass was directed

toward the right mainstem bronchus. The catheter was advanced into the

endotracheal tube until an obstruction is met. The catheter was withdrawn and

rotated while applying an intermittent negative pressure of 100 mm Hg. The

length of the procedure did not exceed ten seconds. Following removal of the

suction catheter, the patient received five breaths of 100% oxygen at 135% of

tidal volume via the mechanical ventilator using the manual breath button. This

protocol is based on current recommendations for endotracheal suctioning of

adults, from the American Association of Critical-Care Nurses and the American

Association of Respiratory Care (AARC, 1993). A second and third suctioning

event followed after it is determined by the investigator that the patient had

recovered from the first suctioning event by monitoring the heart rate, cardiac

rhythm, arterial oxygen saturation levels, and patient response. The anatomy of

the carina (where the left and right main stem bronchus branch) favors passage

of suction catheter into the right mainstem bronchus. In an attempt to increase

the probability that the catheter entered the left mainstem bronchus at least

once, the second and third suctioning passes were directed toward the left side.

XXXXX   1st Sx   XXXXX   2nd Sx   XXXXX   3rd Sx   XXXXX
         (Right)   (Left)   (Left)

Note. X = Manual ventilator breaths (135%Tv; FiO2=1.0)

Figure 4: Suctioning Protocol

Measurement:

Lung Sounds

All lung sound recordings were first analyzed using MATLAB© for

Windows (1993). MATLAB is a technical computing environment for high-

performance numeric computation and visualization. MATLAB allows for

playback the digitized sounds and visual display of the sounds' waveforms.

Using the playback function, each microphone was listened to individually. The investigator noted any adventitious lung sounds audible on the recording for future analysis.

Lung Sound Waveforms

The visual display function of MATLAB presents the waveforms from all seven microphones one on top of the other in a compressed time mode. It is possible to view the entire 10 second recording on the computer monitor. The amplitude of the sound is displayed horizontally and time vertically, running from left to right. This display format was particularly helpful in identifying inspiration and expiration. The duration of the respiratory cycle is determined by viewing the waveforms recorded by the seventh microphone over the sternal notch and trachea. The tracheal microphone records the sounds generated by airflow through the trachea. All lung sound recordings are started at the end of expiration. As a result, the first waveform pattern captured by the tracheal microphone represents inspiration. The second waveform pattern represents expiration (see Figure 5). Using this method, it is possible to measure the duration of inspiration and expiration. Adding inspiration and expiration will yield the duration of one respiratory cycle. Dividing the duration of a continuous sound over two respiratory cycles by the duration of two respiratory cycles yields the percentage of the respiratory cycle occupied by the continuous sound. The beginning and end of each inspiration and expiration was identified and recorded.
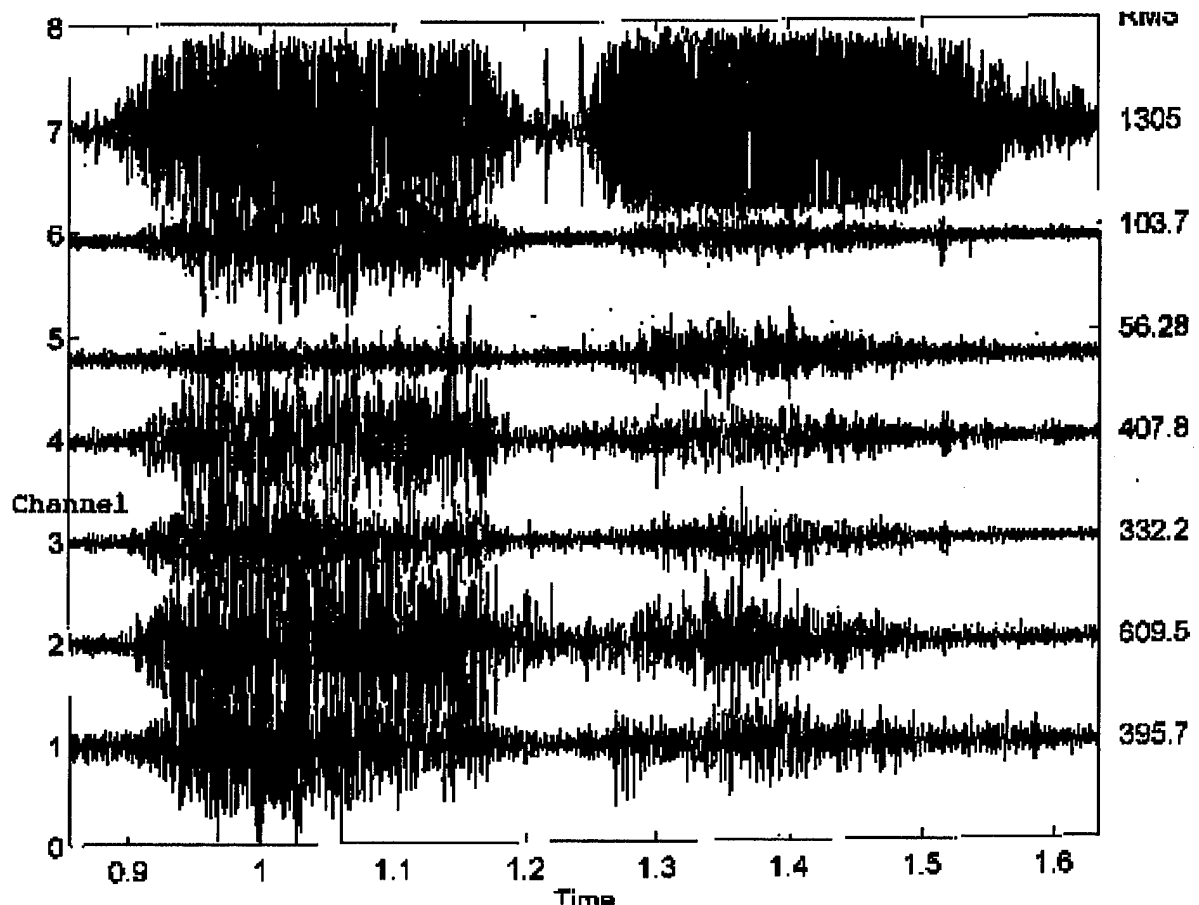
Figure 5. Waveforms of inspiration and expiration, channel 7 (MATLAB)

Note. Channel 7 (top waveform) depicts inspiration and expiration

The waveforms were then analyzed in the time expanded mode using

NEWGRIF© (1992). NEWGRIF displays the waveforms in a similar form as

MATLAB, except the time scale is exaggerated (see Figure 6). Rather than

viewing the entire ten second recording at once, NEWGRIF displays the data in

140 millisecond increments (or 72 computer screens per ten second recording).

The waveform patterns representative of each adventitious sound were

identified by the investigator and research assistant together. The results were

reviewed for accuracy by a TEWA expert. The adventitious lung sounds were classified as wheezes, rhonchi, rhonchi type II, crackles, or coarse sounds.

The quantity of continuous lung sounds (wheezes, rhonchi, rhonchi type II and coarse sounds) was determined using the percentage of at least two respiratory phases in which each sound was present (Loudon, 1993). Rhonchi and wheezes typically display similar patterns on the computer monitor. To differentiate them further, their peak frequencies were determined using a Fast Fourier Transformation (FFT). FFT is a mathematical transformation of the time domain to the frequency domain.

The ACCP-ATS (1977) guidelines state that the dominant frequency of wheezes is 400 Hertz or more and the dominant frequency of rhonchi is 200 Hertz or less. However, we discovered continuous adventitious lung sounds with dominant frequencies between 200 and 400 Hz. These sounds were classified as wheezes.
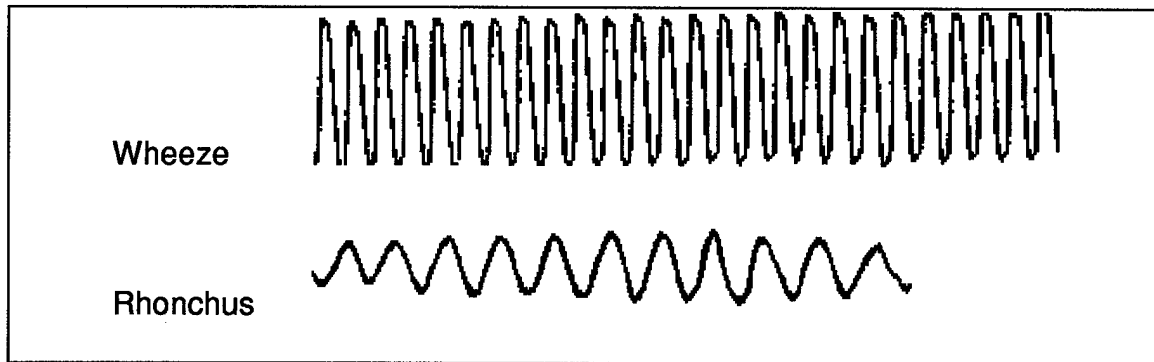
Figure 6. Wheeze and Rhonchus Waveforms on TEWA

The quantity of discontinuous lung sounds (crackles) was counted as individual units. Crackles were first identified on the computer screen by their characteristic waveform and then measured using the following parameters: initial deflection width (IDW) (is the time in milliseconds form the beginning of the crackle event to the first zero crossing of the baseline); two-cycle duration (2CD) (is the time in milliseconds from the beginning of the crackle event to the conclusion of two complete cycles or four zero crossings of the baseline); and zero-crossings (ZCS) (the total number of zero crossings in each crackle event) (Bettencourt, Del Bono, Spiegelman, Hertzmark, & Murphy, 1994). If the measurements fell within the known parameters of crackles, the waveform was categorized as a crackle.

Crackle Criteria:
IDW = B - A   (Minimum = 0.3; Maximum = 1.8)
Fine Crackle = IDW 0.3 - 0.7   Medium = IDW 0.8 - 1.1   Coarse = IDW 1.2 - 1.8
2CD = C - A
Zero Crossings = number of baseline crossings by waveform.
          (Minimum = 4; Maximum = 12)
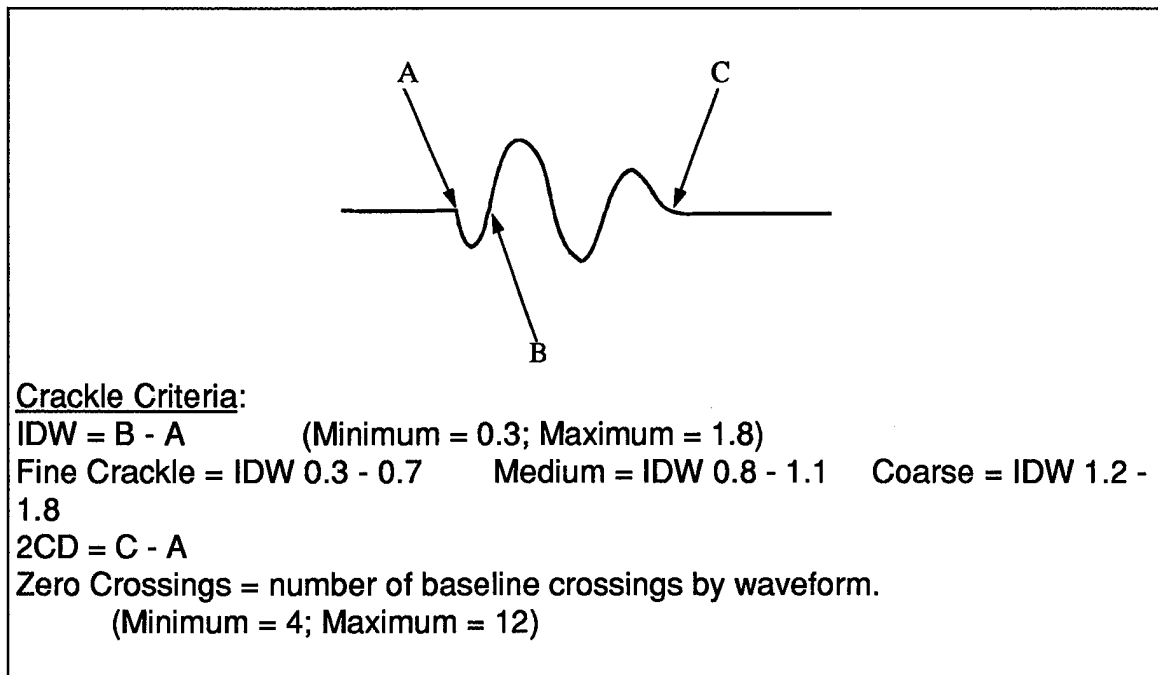
Figure 7. Typical crackle waveform and measurement

The timing in relation to the respiratory cycle is measured by determining

the location of each adventitious sound in the respiratory cycle. The sounds

were categorized as occurring in either inspiration or expiration. As with

measuring the duration of continuous sounds, the microphone over the sternal

notch allows for determining the location of inspiration and expiration on the

computer monitor.

Tracheobronchial Aspirate: The secretions obtained from the three

successive suctioning events were collected using an in-line sputum trap. The

suction catheter was cleared using 10 cc's of sterile saline. Prior to data

collection, it was found that 10 cc's of solution was required to clear the suction

catheter of secretions (flush them into the collection trap). In addition, 0.2 cc of saline adhered to the lumen of the tubing and did not reach the trap.

The tracheobronchial secretions obtained during ETS were weighed and measured for volume. The suction trap, tracheobronchial aspirate, and normal saline flush was weighed using a Mettler© Instrument Corp. electronic scale Model K7T (calibrated by Caley & Whitmore Corp. on 7/21/95). The weight of the suction trap and saline was subtracted resulting in the weight of tracheobronchial aspirate. All weight measurements were performed twice. The secretions were poured into a graduated cylinder calibrated in 0.1 cc increments for measurement of volume. 9.8 cc's was subtracted from the total volume measured, resulting in the net return.

DSxN Instrument:

The nurse placed an X on a 100 millimeter, horizontal line adjacent to 13 clinical indicators for suctioning. Two indicators, "mucus visible in tube" and " rhonchi" were listed twice as an indicator of the tool's reliability. Each indicator was scored by measuring, in millimeters, from the left end of the line to the point where the X intersected the line. The possible scores range from zero to 100.

Protection of Human Subjects

Subject Recruitment and Obtaining Consent

Patients on Mechanical Ventilators

The subject population consists of men and women over the age of 18 who volunteered (or whose family gave consent). Individuals from any racial/ethnic group were allowed to participate. The sources of research materials included specimens (tracheobronchial aspirate) and data (computerized lung sound recording & demographic data). The research protocol called for use of existing specimens. Aspiration of tracheobronchial secretions is normally performed on ventilator patients. Rather than discarding the aspirate immediately, the weight and volume was first measured. In addition, use of existing demographic data on each patient was employed. Finally, computerized lung sound recording was obtained specifically for this study.

A verbal explanation of the study was provided to the subject and next-of-kin. The study was summarized in writing and given to the subject's next-of-kin for future reference. A written consent was obtained before inclusion of the patient in the study. The explanation included the fact that ETS is a routine procedure for these patients and that no unusual treatment would be performed. The next-of-kin was encouraged to ask questions and assured that if they did not want the patient to participate in the study, medical and nursing care would in no way be compromised. The family could request withdrawal of the patient from the study at any time. A code number was assigned to each subject.

Confidentiality is assured by reporting only aggregate data and findings in communicating the results of this study.

Primary Nurse:

The subject population consist of 16 Registered Nurses caring for the ventilator patients listed above who volunteered to participate. Men and women from any racial/ethnic group are allowed to participate. The subject population was sampled from Registered Nurses working in one of two critical care units at one metropolitan teaching hospital. The sources of research materials included data from the Decision to Suction Now (DSxN) instrument and demographic data. The investigator explained the purpose of the study and the role of the primary nurse. The nurses were informed that participation was voluntary, that they could withdraw at any time, and refusal to participate would not impact their employment status. Confidentiality is assured through the use of coded identification numbers.

Criteria for Removal from Study

While ETS is a routine nursing measure for intubated patients, care was taken to assess the patient's responses during the suctioning protocol. The procedure would be terminated for the same clinical indicators that routine ETS would be terminated. The investigator was responsible for assessing the patient's response and terminating the procedure.

Criteria for terminating endotracheal suctioning: 1) rise in heart rate of 20 beats per minute or more, lasting 3 minutes; 2) presence of life threatening cardiac

arrhythmias (e.g. premature ventricular contractions greater that 6/minute, symptomatic bradycardias, etc.); 3) rise in mean arterial blood pressure of 30 mm. Hg. or more lasting three minutes; 4) drop in arterial oxygen saturation below 90% for more than 30 seconds, and 5) investigator's clinical judgment that patient was not tolerating the procedure. It was not necessary to terminate the suctioning procedure on any patient.

Controls in the Research Design

Cook & Campbell (1979) describe internal and external validity in relation to research. Internal validity is the degree to which the variables under study, rather than some extraneous variables, are responsible for the research findings. They identified twelve types of extraneous variables that, if left uncontrolled, may produce effects which could be mistaken as the effect of the variables under study. Threats to the internal validity of this study were controlled using a variety of methods.

Threats to Internal Validity

Instrumentation was controlled for by reanalyzing the waveform data three times. The potential that the ability of the investigator to identify waveform patterns may have changed over the course of the study. It is reasonable to anticipate improvement in the ability of the researcher to identify waveform patterns. To control this, the lung sound data was reanalyzed twice.

Threats to External Validity

The reactive effects of the investigators recording lung sounds may have heightened the nurses' awareness of the role of lung sounds in their judgment to suction. The nurses' responses to why they decided the patient required suctioning may have been affected by their knowledge of the focus of this study. To control for this, the investigator met with each nurse prior to data collection and emphasized the importance of candid answers.

Chapter Summary

Although the research questions presented in chapter one are uncomplicated, the methods and procedures outlined in this chapter were relatively complex. The methods for lung sound mapping were designed to capture an accurate picture of the upper airways both before and after suctioning. Since there exists no specific guidelines for when suctioning should be performed, the decision was made by the primary nurse.

CHAPTER 4

Presentation, Analysis and Interpretation of Data

Introduction

The purpose of this study was to describe lung sound patterns in patients

requiring endotracheal suctioning. The study design and data collection

procedures were conceptualized in a mucus accumulation - lung sound

generation framework. In this chapter, the characteristics of the sample, data

analysis procedures, and analysis of each research question will be provided.

Finally, a discussion of the results of research questions and anecdotal

observations will be presented.

Characteristics of the Sample

Ventilator Patients

Fifteen patients or their next-of-kin consented to participate in the study

over a five month period. All (N = 15) who were approached for consent

volunteered to participate in the study. The mean age for the sample was 70

years old with a range of 45 to 90 (SD = 12.27). There were seven women

(47%) and eight men (53%). All the patients were endotracheally intubated and

mechanically ventilated as treatment for Acute Respiratory Failure (ARF). Three

patients (20 %) received mechanical ventilation as part of their post operative

trajectory (status post: Whipple procedure, nephrectomy and hemicolectomy).

The remaining 12 patients had a myriad of medical etiologies of their ARF (see

Table 1). The most common medical diagnosis was pneumonia (N = 3). In

addition, COPD and CHF were listed as comorbid diseases in three patients

each (20%).

Attrition of the original 15 subjects occurred over time for two reasons: 1)

improvement of the patient's clinical condition to a point were mechanical

ventilation was no longer required (N = 7) and 2) death (N = 1). As a result of

these changes in the patients' condition over time, 15 patients were recorded at

Time 1, 13 (87%) at Time 2, 10 (67%) at Time 3 and Seven (47%) at Time 4.

Table 1.

Etiologies of ARF and Comorbid Conditions

Subject	Diagnosis	Comorbid Conditions
1	Congestive Heart Failure (CHF)	
2	Chronic Obstructive Pulmonary Disease (COPD)	
3	Respiratory Depression, secondary to opiates	COPD, CA
4	S/P Whipple	
5	S/P nephrectomy	
6	S/P cardiac arrest	
7	Hypothermia	COPD, CHF
8	Pneumonia	
9	S/P cardiac arrest	CHF
10	Pneumonia (PN)	COPD
11	Seizure	CHF
12	Rib fracture	PN, Lung cancer
13	S/P hemicolectomy	Ulcer
14	Upper GI bleed	Ulcer
15	Pneumonia	Multiple sclerosis

Critical Care Nurses

Sixteen nurses participated in the study by completing the DSxN instrument. All the nurses approached by the investigator volunteered to participate. These nurses had an average of 11 years of nursing experience. Most of nurses had a Bachelor's degree (60%) and reported they cared for patients who required endotracheal suctioning on a daily basis.

Data Analysis Procedures

The data were coded and entered into a microcomputer. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS© for Windows) Version 6.1. Descriptive statistics were computed for all study variables. It was noted that the scores for all adventitious lung sounds where not normally distributed and had little variability. For example, at Time 1, 11 (73%) of the patients had no rhonchi prior to suctioning. This trend was noted for the other categories of adventitious lung sounds as well, 9 (60%) had no wheezes; 10 (67%) had no crackles; 9 (60%) had no type II; and 8 (53%) had no coarse sounds before suctioning. As a result, descriptive statistics were used to search for patterns of lung sound before and after suctioning (research questions 1 & 2). Nonparametric statistics were used to evaluate the relationship between: lung sounds and the volume of sputum (question 3), and perceived and recorded rhonchi (question 4). For question 3, the sample population was divided into dichotomous groups according to whether or not they had a particular sound. The two groups for each sound were compared

using a Mann Whitney U statistic with the volume of endotracheal aspirate as the dependent measure. Research question 4 was addressed using Mann-Whitney U statistic. The subjects were grouped according to whether or not they had rhonchi at Time 1. The dependent variable was the score on the rhonchus item of the DSxN.

<div align="center">Analysis of Research Questions</div>

Research question #1: What is the pattern of adventitious lung sounds before suctioning?

No pattern of adventitious lung sounds prior to endotracheal suctioning was identified. The data were classified by: lung sound category, frequency and quantity, timing and locations. Comparisons within subjects over time and between subjects at Time 1 failed to reveal any patterns.

Classifications of Adventitious Lung Sounds

Five adventitious lung sound waveforms were identified during time expanded waveform analysis. Three of the lung sounds had waveform characteristics which matched the sounds described in the ATS nomenclature (rhonchi, wheezes and crackles). In addition, two sounds with acoustic characteristics not classified in the ATS nomenclature were identified. These sounds were labeled type II rhonchi and "coarse sounds." Coarse sounds were loud and harsh in character with a high amplitude waveform in TEWA. Type II rhonchi had an intermittent undulating waveform in the time expanded mode. In

an effort to prevent confusion between the two types of rhonchi, rhonchi will be referred to as type I rhonchi.

In addition to the waveform morphology, the acoustic properties of the sounds were analyzed using spectral analysis. Fast Fourier Transformation (FFT) is a method of spectral analysis which provides information about the range of frequencies within a sound. Type I rhonchi were observed with a dominant frequency ranging from 78 to 194 Hz (mean = 114 Hz); wheezes from 202 to 446 Hz (mean = 278 Hz); type II rhonchi between 100 and 150 Hz (mean = 125 Hz); and coarse sounds from 50 to 150 Hz (mean = 100 Hz).

Quantity of Adventitious Lung Sounds

Adventitious lung sounds were identified in less than half the subjects. All sounds occurred with approximately the same frequency. coarse sounds were present in seven (47%); wheezes in six (40%); type II rhonchi in six (40%); crackles in five (33%); and type I rhonchi occurred in four (27%) of the 15 subjects measured at Time 1.

Number of Subjects With Adventitious Sounds
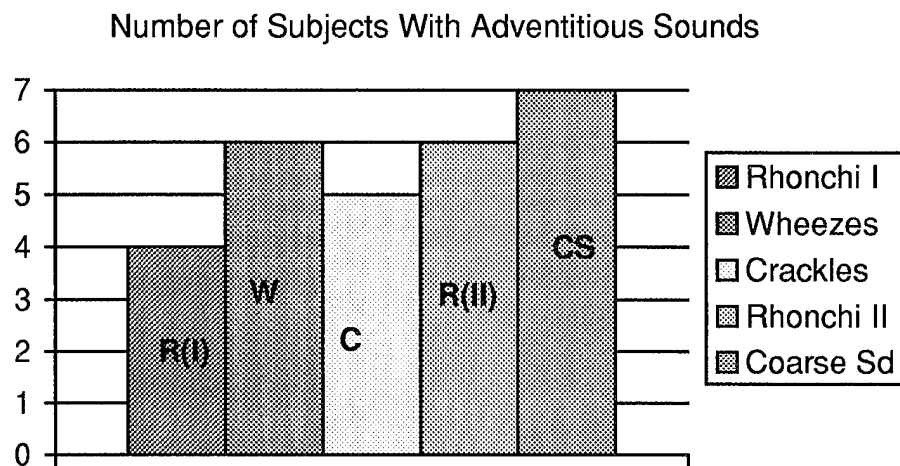
Figure 8. Occurrence of adventitious lung sounds at time 1.

<u>Timing: inspiration -vs.- expiration</u>

The lung sounds were categorized according to their location in the

respiratory cycle (inspiration, expiration or both inspiration and expiration). No

pattern of lung sounds was identified in relation to the respiratory cycle. In other

words, each sound was recorded equally as often in inspiration and expiration,

except for coarse sounds. Coarse sounds occurred in inspiration or both

inspiration and expiration but never in expiration alone (see Figure 9).

Adventitious Sound	N	Subject	Inspiration	Expiration	Both	Loudest Location
Type I rhonchi	4	2		X		anterior
		6	X			anterior
		9		X		anterior
		10	X			anterior
		Totals	2	2	0	4 anterior
Wheezes	6	2	X			posterior
		7	X			posterior
		9			X	anterior
		10		X		posterior
		11	X			lateral
		12		X		posterior
		Totals	3	2	1	4 posterior 1 anterior 1 lateral
Crackles	5	2		X		anterior
		3	X			lateral
		9			X	anterior
		10	X			anterior
		13			X	anterior
		Totals	2	1	2	4 ant 1 lat
Type II Rhonchi	6	2			X	anterior
		3		X		anterior
		4	X			anterior
		6	X			anterior
		7	X			posterior
		9			X	anterior
		Totals	3	1	2	5 anterior 1 posterior
Coarse Sounds	7	5	X			anterior
		9			X	anterior
		10	X			anterior
		12			X	anterior
		13	X			anterior
		14			X	anterior
		15	X			lateral
		Totals	4	0	3	6 ant/1 lat

Figure 9. Adventitious Lung Sounds Recorded Prior to Suctioning at Time 1.

Location

Using computerized lung sound analysis, it is possible to determine where the sounds can be heard over the chest and where the sound is the loudest. The microphone locations were categorized as anterior (microphones 1 and 4), lateral (microphones 2 and 6), and posterior (microphones 3 and 5). Wheezes were loudest at microphones located over the posterior chest. All other adventitious lung sounds were loudest at microphones located over the anterior chest.

The type of adventitious sound was examined in relation to the site of observation. Each type of adventitious sounds were observed at the three locations over the chest. Type I rhonchi, crackles, type II rhonchi and coarse sounds were most often recorded by the anterior microphones. Wheezes were recorded equally at the anterior and posterior positions.

Pattern of Lung Sounds Over Time

Lung sounds were recorded at three time intervals on 10 subjects (Table 2). No consistent lung sound pattern was identified in the same subject over multiple recordings.

Table 2

Variation in Patterns of Lung Sounds Observed in the Same Subjects on 3

Separate Occasions.

Subj	Time 1					Time 2					Time 3				
	Rh	Wh	Cr	T2	Cor	Rh	Wh	Cr	T2	Cor	Rh	Wh	Cr	T2	Cor
2	X	X	X	X				X		X				X	X
6	X			X		X				X	X				
7		X		X		X	X			X					X
9	X	X	X	X	X	X		X	X	X		X		X	X
10	X	X	X		X		X			X					
11		X					X		X	X		X	X		
12		X		X			X		X	X					X
13			X	X		X					X	X			
14				X											
15				X				X		X				X	X

Note. X denotes the sound was present. Rh=type I rhonchi, Wh=wheeze,

Cr=crackle, T2=type II rhonchi, and Cor=coarse sound.

Research question #2: Change in Lung Sounds After Suctioning

     In the seven subjects who had coarse sounds before suctioning, there

was a reasonably consistent change in the duration of these sounds after

suctioning. In addition, there was a 35% reduction in the total occurrence of adventitious lung sounds after suctioning. No other pattern was identified. As with the data obtained before suctioning, adventitious lung sounds occurred infrequently.

Quantity

Adventitious lung sounds rarely occurred after suctioning. Type I rhonchi were the most frequently occurring adventitious lung sound. Type I rhonchi were present in five (33%); type II rhonchi in four (27%); coarse sounds in four (27%); wheezes in three (20%); and crackles in one (7%); of the 15 subjects at Time 1 (Figure 10).

The totals for lung sounds before suctioning (Figure 8) and after suctioning (Figure 10) demonstrate an overall reduction in the occurrence of total lung sounds. Before suctioning, a total of 28 adventitious lung sounds were recorded in 12 subjects. After suctioning, that total declined by 35 percent to 17 sounds in ten subjects.

Sound	N	Subject	Inspiration	Expiration	Both	Loudest Location
Type I rhonchi	5	1	X			anterior
		4			X	anterior
		6			X	anterior
		9		X		anterior
		11	X			anterior
		Totals	2	1	2	5 anterior
Wheezes	3	1	X			posterior
		9			X	anterior
		10		X		posterior
		Totals	1	1	1	2 post 1 anterior
Crackles	1	15	X			1 lateral
		Totals	1	0	0	1 lateral
Type II Rhonchi	4	1	X			lateral
		4	X			anterior
		6	X			anterior
		11		X		anterior
		Totals	3	1	0	3 ant/1 lat
Coarse Sounds	4	3			X	anterior
		9			X	anterior
		12	X			anterior
		13	X			anterior
		Totals	2	0	2	4 anterior

Figure 10. Adventitious Lung Sounds Recorded After Suctioning at Time 1

In addition to whether an individual sound occurred or not, the quantity (number or duration of the sound) was measured and evaluated. Of the five sounds, only coarse sounds consistently decreased in duration after suctioning. In the seven subjects with "coarse sound" waveforms present prior to suctioning, six (86%) showed decreases in duration and one (14%) was unchanged after suctioning. The average decrease in the duration of this sound was 15 percent.

Table 3

Change in Coarse Sounds After Suctioning at Time 1

Subject	Duration Before Suctioning	Duration After Suctioning	Change
5	17	0	decreased 17%
9	40	40	unchanged
10	22	0	decreased 22%
12	61	50	decreased 11%
13	34	30	decreased 4%
14	29	0	decreased 29%
15	5	0	decreased 5%

Similar decreases in the duration of coarse sounds were observed at Time 2. Nine of the 13 subjects had coarse sounds prior to suctioning. Of these, six (67%) demonstrated a decrease in the duration of the sound by an average of 32 percent. One subject's (11%) "coarse sound" was unchanged. However, two subjects (22%) showed increases in the duration by an average of six percent.

Timing:

No pattern in relation to the respiratory phase was identified. All adventitious lung sounds were present in inspiration and expiration after suctioning. Each sound was recorded equally as often in inspiration and expiration, except for coarse sounds. Coarse sounds occurred in inspiration or both inspiration and expiration but never in expiration alone.

Location:

Wheezes were loudest at microphones located on the posterior chest. All other adventitious lung sounds were loudest at microphones located on the anterior chest. This is the same pattern identified in lung sounds recorded prior to suctioning.

Adventitious lung sounds were recorded at all three locations. Type I rhonchi, Type II rhonchi and coarse sounds were recorded more often by the anterior microphones. Wheezes and crackles were recorded equally by the anterior and posterior microphones.

Research question #3: Relationship between lung sounds and volume of mucus?

There was no relationship between the presence of individual abnormal lung sounds and the volume of aspirate obtained from endotracheal suctioning. The sample was divided according to whether or not a particular sound was present. These groups were compared using the volume of aspirate as the

outcome measure. None of the comparisons showed statistical significance (see

Table 4).

Table 4

Effect of Adventitious Lung Sounds on Volume of Aspirate Obtained

Lung Sounds before suctioning	Median Volume (cc) of Aspirate for time 1 (N=15)	Mann-Whitney U Z Score	2-tailed p
Type I rhonchi	1.10 (N=4)	-0.20	0.84
No type I rhonchi	1.20 (N=11)		
Wheezes	1.10 (N=6)	-0.12	0.91
No wheezes	1.20 (N=9)		
Crackles	1.00 (N=5)	-0.61	0.54
No crackles	1.20 (N=10)		
Type II Rh	1.20 (N=6)	-0.24	0.81
No type II Rh	1.19 (N=9)		
Coarse sound	1.00 (N=7)	-0.87	0.38
No coarse sound	1.35 (N=6)		

Research question #4: Relationship between perceived and actual rhonchi?

There was no difference in the nurses' score of the importance of rhonchi in the decision to suction between subjects grouped according to whether or not they had type I rhonchi present prior to suctioning (Z = - 1.44, p = 0.15).

Interpretation and Discussion of Research Questions

Research Question 1 (pattern of sounds prior to suctioning)

The review of the literature suggested that patients requiring endotracheal intubation commonly developed adventitious lung sounds as a result of secretion accumulation. Of the 15 subjects, 13 had abnormal sounds prior to suctioning. Although five different adventitious lung sounds were identified, they did not occur as often as expected and a pattern of adventitious lung sounds was not observed. The results from three subjects demonstrates the divergence in lung sounds present prior to suctioning. For example, subject 9 had all five categories of adventitious lung sounds, subject 15 only had coarse sounds and subject 8 didn't have any adventitious lung sounds. The following is a discussion of the results of this study as they relate to each lung sound.

Type I Rhonchi

One of the most startling results of this study is how infrequently type I rhonchi were recorded. The literature encompassing endotracheal suctioning and lung sounds is laden with works citing rhonchi as the most common sound (Knipper, 1986; Shekleton & Nield,1987). In addition, Thompson, Wiggins, &

Sims (1994) used expert nurses opinion to corroborate the notion that type I rhonchi are common in this population of patients.

Only one research study actually measured type I rhonchi in patients with artificial airways (Hoogendoorn & Murphy, 1990). Unfortunately these authors did not report how often type I rhonchi were present in the eight patients they measured. Instead they reported only the number of recording sites where a rhonchi was detected ("positive sites"). Based on the maximum possible number of sites for the study, it appears as if most of the eight patients they measured had type I rhonchi.

Wheeze

Prior to initiation of the study, it was unknown what pattern of wheezes would be recorded. The literature offers several theories for the generation of wheezes. One of the most popular explanations states that a wheeze is caused when airflow is limited and the airway flexibility allows oscillations to evolve (Koster, Baughman & Loudon, 1990). These conditions are often caused by airway narrowing secondary to bronchoconstriction, interstitial swelling or mucus accumulation. Thus, it was considered possible to find wheezes in patients with artificial airways.

Another factor affecting the results of this study is the method by which wheezes were defined. The major criterion used to discriminate between wheezes and type I rhonchi is the dominant frequency of each. The ATS criteria states that the frequency of wheezes is usually greater than 400 Hz and less

than 200 Hz for type I rhonchi. There is, however, little objective evidence in the literature to support the ATS criteria. Several continuous lung sounds were recorded with dominant frequencies in the range of 200 to 300 Hz. This sounds were classified as wheezes based on the advice of a lung sound expert who listened to the sounds. The key point of this discussion is that the dominant frequency of the continuous sounds were not neatly separated as the ATS nomenclature suggests. Rather there appears to be a continuum of frequencies for continuous lung sounds. For example, one rhonchus was measured with a frequency of 194 Hz and one wheeze at 202 Hz.

The separation between the dominant frequency of wheezes and type I rhonchi was blurred in these subjects. It is possible that this narrowing of the gap may have made it difficult for the nurse to discriminate the sounds using a stethoscope. The results of this study do not clarify whether a persistent pattern of wheezes is present prior to suctioning.

Crackles

Crackles were not frequently recorded prior to suctioning. Two factors were identified during data collection which may account for this relative lack of crackles. 1) The microphones were placed in positions over the major airways. Since the suction catheter does not reach beyond the carina, it was important to record the sounds generated from this area. However, clinical experience suggests that crackles arise from the snapping open of smaller airways located most commonly in the lung bases (Bettencourt et al, 1994). If this is true, the

microphones may have been positioned too high on the thorax to record the majority of crackles. 2) The waveforms of crackles may have been masked or covered by the larger continuous lung sounds. Although spectral analysis of the sound can identify sounds not visible in the time domain, it is not sensitive enough to detect a single crackle.

Type II Rhonchi

Type II rhonchi were first identified by Hoogendoorn & Murphy (1990) in a study of lung sounds in patients with artificial airways. They described this sound as having an undulating pattern on TEWA similar to type I rhonchi, however the pattern was interrupted intermittently (see Figure X). This waveform has not been discussed in the literature since it was first discovered. It is possible, that type II rhonchi are particular to patients with artificial airways, mechanical ventilation or a combination of the two.

Unfortunately, Hoogendoorn & Murphy did not describe how type II rhonchi sounds to the human ear. This may have been due to technical limitations of their study. In this study, it was possible to determine the exact location of the waveform and playback the sound using MATLAB. However, it was impossible to differentiate the type II sound from the sounds produced by the ventilator and/or patient in this study.

Figure 11. Type II rhonchi waveform on TEWA

Type II rhonchi may not have a perceptible pitch. Rhonchi and wheezes last longer than 250 milliseconds (a quarter of a second). The duration seems to be partially responsible for their "musical" quality. However, the sine wave portion of the Type II rhonchi rarely lasts longer than 50 milliseconds before it loses its pattern. The spectral analysis of these sounds demonstrated a dominant frequency between 100 and 150 Hz. This is similar to the frequency range of type I rhonchi. Although it was impossible to describe the type II rhonchi, it was obvious that it did not sound like a type I rhonchi. The role of type II rhonchi in understanding lung sounds in this population of patients remains unclear.

Coarse Sounds

Coarse sounds is a label given to a sound commonly observed in this study. When this waveform pattern was initially encountered during time expanded analysis, it was discounted as an unknown sound, possibly background noise. On playback it had a "roughness" in character that was different than in normal subjects. The sounds did not have a perceptible pitch or "musical" quality and they did not sound like a type I rhonchi. Indeed clinicians commonly use the term coarse breath sounds although the acoustic characteristics haven't been described. The waveform pattern of coarse sounds was encountered both in the same subjects at different suctioning episodes and

in different subjects. As a result, it was categorized as an adventitious sound

and included in the study.

The waveform of these coarse sounds demonstrates an irregular

undulating pattern with a very high amplitude (see Figure 12). The waveform

does not match any of the known lung sounds. coarse sounds can be classified

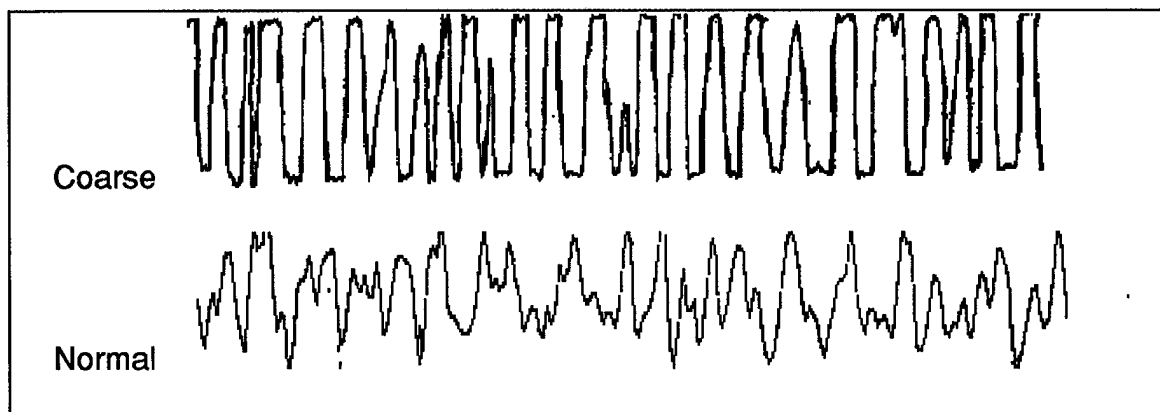as a continuous sound, lasting more than 250 milliseconds.

Figure 12. Comparison of coarse sounds and normal waveforms at microphone

1

The pattern of coarse sounds was easy to identify on TEWA in different

subjects. Although the period between waves is irregular, the overall

morphology of the waveform is distinctive and does not match the typical chaotic

waveforms seen in normal non-intubated subjects (see Figure 12) Although the

waveforms depicted in the time expanded mode are good markers for each

adventitious sound, their appearance can be masked by other sounds occurring

simultaneously. Spectral analysis has been shown to be useful in identifying

adventitious sounds not visible in the time domain (Koster, Baughman & Loudon,

1990). The spectral analysis (FFT) of coarse sounds showed a dominant frequency of between 50 and 150 Hz. This is within the frequency range of type I rhonchi. There is a possibility that these coarse sounds are related to type I rhonchi.

In the studies by Amborn (1976) and Knipper (1984), adventitious lung sounds were referred to as "coarse lung sounds". Since these authors did not use the ATS nomenclature, it was presumed that they were referring to type I rhonchi, since type I rhonchi have been described as having coarse qualities. It is possible that these investigators were measuring a sound that did not fit the ATS criteria.

Nurses commonly use different terms to describe the lung sounds of ventilator patients (e.g. "junky", "wet", or "coarse"). It has been implied that the reason for this departure from the standardized terminology was due to ignorance on the part of the nurse. There is a possibility that the nurses use these other labels in an attempt to describe a different sound. Coarse sounds are the most common adventitious lung sound in this population and will require further study.

<u>Lung Sounds Measured Over Time:</u>

Another unexpected finding from this study was that the same types of

lung sounds were not present in the same subject on subsequent measures.

Subject 10 is a good example of the variability in lung sounds recorded at

different times. This subject had type I rhonchi, wheezes, crackles and coarse

sounds at Time 1; crackles and coarse sounds at Time 2; and no adventitious

sounds at Time 3.

One possible explanation for the variability in lung sounds in this study

can be attributed to the lack of control of the interval between suctioning

episodes. Since the time between suctioning episodes was not controlled, the

internal validity of the study may be threatened by history. Many variables may

have changed over the span of multiple measurements. As mentioned earlier,

attrition of subjects was most commonly caused by improvements in the patient's

condition and extubation. Change in the patients' pulmonary status may account

for the inconsistent pattern of lung sounds over time.

<u>Research Question 2: (Change after suctioning?)</u>

It was anticipated that adventitious lung sounds would be common in this

group of patients. Of these sounds, type I rhonchi were expected to decrease

after suctioning. This conjecture is based on the two related concepts 1) that

type I rhonchi are generated by the flapping of mucus in the airway and 2)

endotracheal suctioning removes mucus from the airways. However, the number

of type I rhonchi did not change significantly after endotracheal suctioning in this

study (Figure 13).

Wheezes did not change significantly after endotracheal suctioning.

Based on the theory that wheezes are a result of airway narrowing, endotracheal

suctioning could have a number of effects on wheeze generation. Endotracheal

suctioning could: 1) remove mucus from an airway, thus eliminating or reducing

the wheeze; 2) remove mucus from an airway, increase air flow to the distal

airways with narrowed airways, thus creating a different wheeze; 3) irritate the

airways, cause bronchonconstriction, and thus create a new wheeze. As a

result, it was not anticipated that wheezes would demonstrate a pattern effected
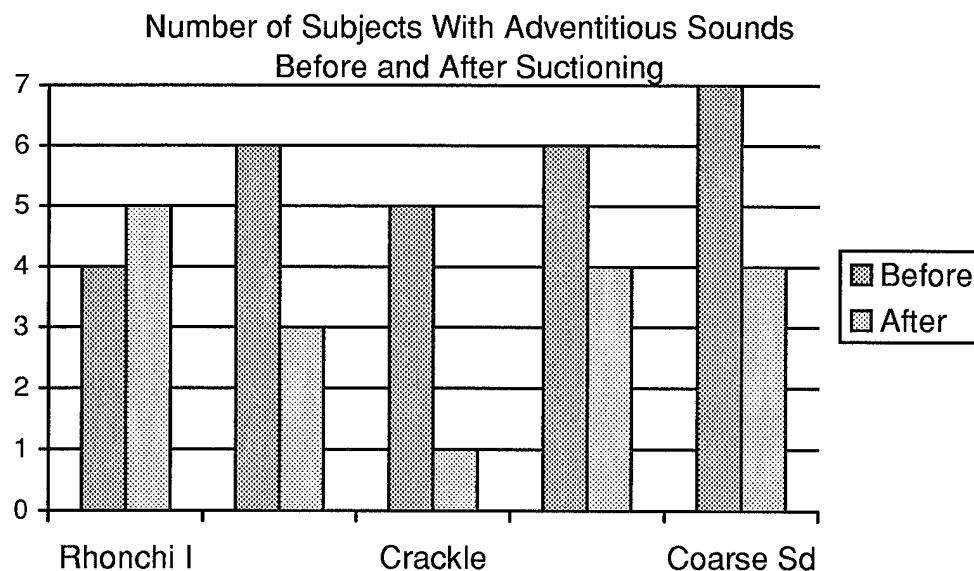
by endotracheal suctioning.

Figure 13. Change in Occurrence of Adventitious Sounds at Time 1

It is conceivable that a sound may occur with the same frequency before and after suctioning. A change in the quantity (e.g. duration) of each adventitious sound after suctioning may also indicate a pattern. The only sound that changed consistently between and within subjects was coarse sounds.
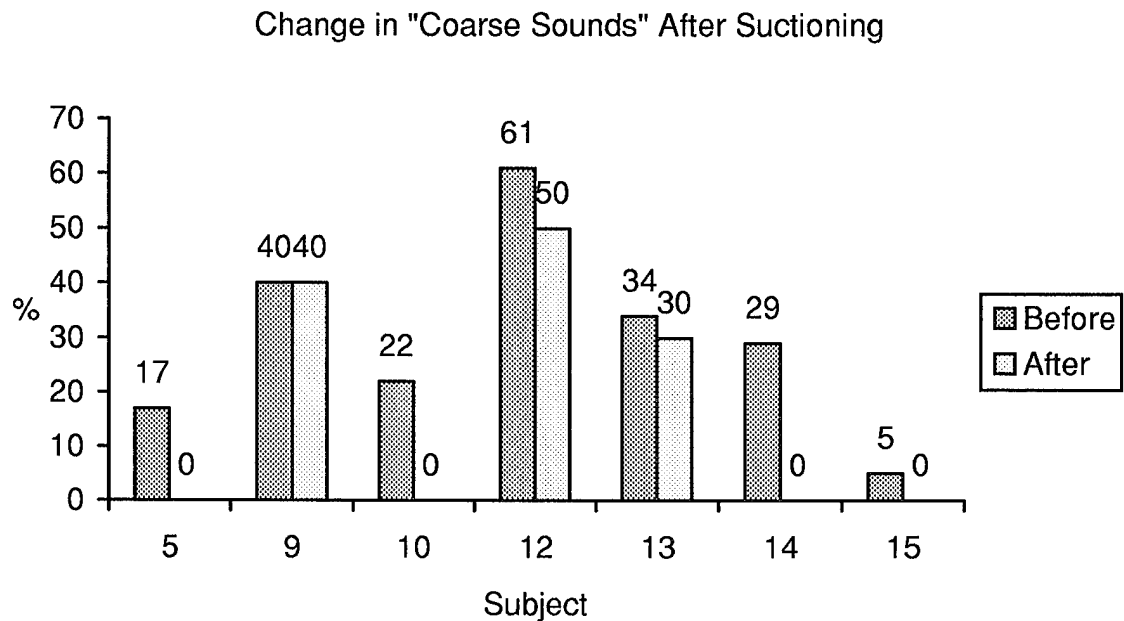
Change in "Coarse Sounds" After Suctioning

Figure 14. Duration of coarse sounds before and after suctioning at Time 1

Timing

The timing of the adventitious lung sounds did not appear to change after suctioning. Most sounds were present in inspiration slightly more than expiration. This was anticipated since airflow through the respiratory tract is faster in inspiration. This group of patients was no exception. In fact, the duration of inspiration for these patients was much shorter than normal patients. This is due to the positive pressure mechanics of the ventilator and the movement of air through the endotracheal tube.

Of special interest was the pattern of timing of the coarse sounds. These sounds were never present in expiration alone. Since this sound has not been

previously described, it is not known why the timing of the sound behaves this way.
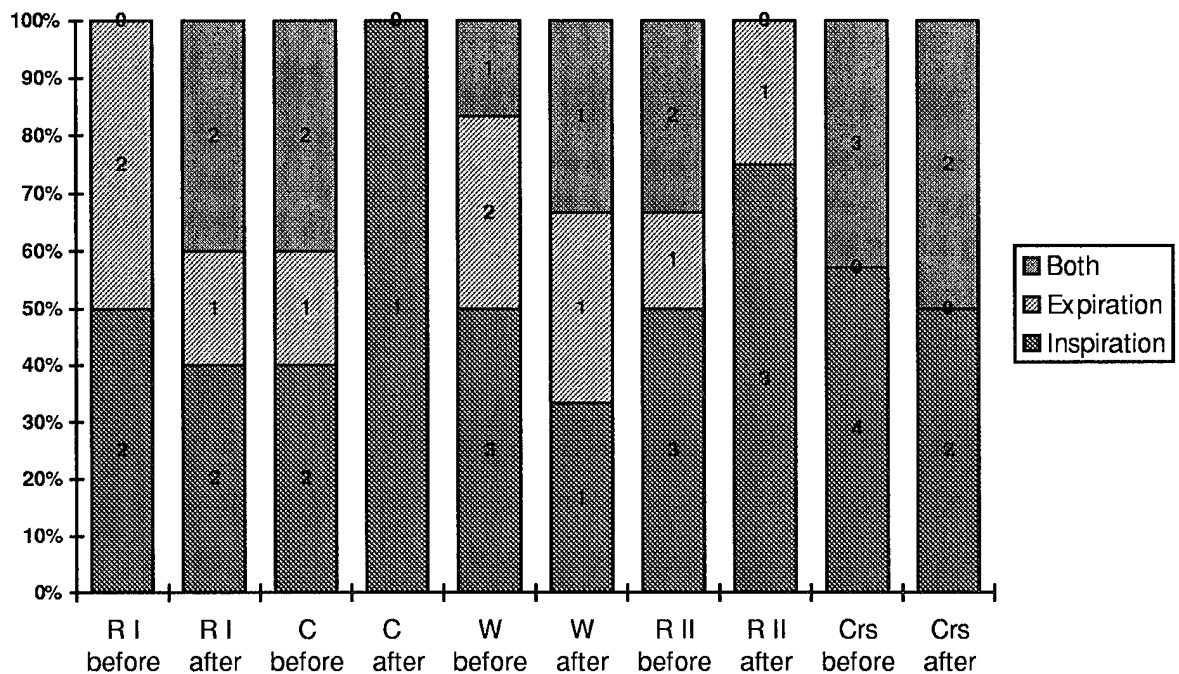

Figure 15. Distribution of adventitious lung sounds over respiratory cycle before and after suctioning at Time 1. Note: R I (type I rhonchi); C (crackles); W (wheezes); R II (type II rhonchi); and Crs (coarse sounds).

Research Question 3: (Relation between lung sounds and aspirate?)

Amborn and Knipper demonstrated a relationship between the presence of added lung sounds and the amount of aspirate obtained. In both studies, the average volume of aspirate was approximately 0.5 cc's. However, in this study no association was found between lung sounds and aspirate despite obtaining twice as much mucus. Subject 8 is a good example of how the results were

counter to what was expected. This subject had adventitious sounds on two separate occasions. In both situations, more than 3 cc of mucus were suctioned from the airway.

The suctioning procedure was blind and had limited range into bronchial airways. Therefore it was not known what percent of the secretions present were cleared by the catheter. In addition, it is unknown whether lung sounds were generated below the reach of the suction catheter.

Although the amount of mucus aspirated in this study was double that reported by others, it still may not have been enough to generate adventitious lung sounds. It remains unknown what the clinically significant amount of sputum is to generate lung sounds and trigger signs and symptoms in the patient that can be observed by the nurse. Certainly, another factor to be considered is the amount of mucus in relation to the size of the subject's airways. Three milliliters of mucus may not be clinically significant in a six foot, 250 pound subject; but in a five foot, two inch, 110 pound individual it may produce symptoms of airway occlusion.

Finally, adventitious lung sounds could have been generated from airways out of reach of the suction catheter. Crackles have already been discussed in relation to this idea. In addition, mucus flaps in the lobar and segmental bronchi would be beyond the range of the suction catheter. If so, they would be unaffected by endotracheal suctioning and continue to generate continuous sounds.

Research Question 4: (Relation between perceived and measured rhonchi?)

There was no difference in the nurses' score of the importance of rhonchus in the decision to suction between the group of subjects with type I rhonchi and the group without type I rhonchi prior to suctioning. This finding was also not anticipated. To the contrary, there was concern that the nurses' responses would be contaminated by reactive effects of knowing that the study was about lung sounds. To better understand why the two groups did not differ, it is helpful to evaluate the rationale for suctioning used by the nurses.

The "time since last suction" was the most frequently used factor in the decision to suction the patient. The "time since last suctioning" was cited as a criteria in 14 (93%) of the 15 suctioning episodes at Time 1. The average score of importance was 74. In contrast, type I rhonchi were mentioned as important by only seven nurses (47%) and the mean importance score was 75. The frequencies and mean importance scores of this study are very similar to those reported by Thompson, Wiggins & Sims (1994). The only difference is that "patient request" was rated as the second most important criteria in their study. This can be attributed to subject sampling. Their study sampled only awake and oriented subjects capable of reporting symptoms. In contrast, five of the subjects from the current study were unresponsive or not oriented.

Seven nurses rated type I rhonchi as important in their decision to suction the patient. However, only three (43%) of those patients had type I rhonchi as measured by time expanded waveform analysis. Of the eight nurses who did not

rate type I rhonchi as important, one (12%) had type I rhonchi and seven (88%) did not.

The agreement between the DSxN rhonchi score and the type I rhonchi actually present were compared. Ten showed agreement (three had type I rhonchi and rhonchi were rated important). Five showed disagreement. One had type I rhonchi but rhonchi were rated unimportant and four had no type I rhonchi but rhonchi were rated important.

In the single case where type I rhonchi were recorded but not rated as important, dyspnea, increased work of breathing, and peak inspiration where rated as important. In the four cases were rhonchi were rated important but no type I rhonchi were present, all had other adventitious lung sounds. Two had coarse sounds, one had a wheeze, and one had type II rhonchi.

These findings appear to indicate that type I rhonchi were not important in the decision to suction for most nurses. Unfortunately, the DSxN does not measure the rationale used by the nurse that would explain why one criteria is more important than another. There are three possible scenarios in which the nurse could have rated rhonchi as relatively unimportant. 1) The nurse listened for lung sounds and rhonchi were not present. 2) The nurse listened for lung sounds, rhonchi were present, however other criteria were more important. and 3) the nurse did not assess lung sounds.

It remains unclear why the mean score of importance for rhonchi was the same for the group with type I rhonchi and the group without type I rhonchi.

Anecdotal Observations

The Decision to Suction Now instrument reliability was 0.99 (p < 0.001). Thompson, Wiggins & Sims reported a similar score (0.96). Combining the data from all 45 suctioning episodes, the five most important criteria were "time since last suction" (68.9), "rhonchus" (45.4), "increased work of breathing" (27.7), "properties of last sputum" (23.5), and "cough" (22.3). The five most frequently used criteria were "time since last suction" (40), "rhonchi" (30), "increased work of breathing" (15), "properties of last sputum" (15), and "decreased breath sounds" (13).

On average, the sixteen nurses involved in this study used 3.9 criteria in the decision to suction. Thompson, Wiggins & Sims (1994) report a mean frequency of 4.7 criteria. The scores for each of the criteria on the DSxN from this study were not predictive of the amount of secretions aspirated.

Chapter Summary

The many of the results of this study were unanticipated. The presence of sound waveforms that did not fit current method of categorization made interpretation of the results complicated. The ramifications of this study reach into the areas of clinical assessment and decision making, nursing practice guidelines and future research in the areas of lung sounds and endotracheal suctioning to be discussed in chapter 5.

CHAPTER 5

Synopsis, Implications for Practice, Recommendations

and Conclusions

Introduction

In this final chapter, a review of the purpose of the study and research

questions will be presented. The implications for nursing practice are described

and recommendations for future research are presented. Finally, conclusions

brought forth from the study are provided.

Synopsis of the Study

The specific aims of this study were to analyze adventitious lung sounds

in patients with artificial airways before and after endotracheal suctioning. In

addition, sounds were evaluated for patterns, connection with aspirate, and

perceptions of the primary nurse. A secondary goal of this study was to

demonstrate that adventitious lung sounds could be recorded, analyzed and

store using a computerized system. To address these aims, the following

research questions were generated:

Research Questions

1. What is the pattern (classification, quantity, timing in relation to the

    respiratory cycle, and location) of adventitious lung sounds present

    immediately prior to ETS?

2. How do adventitious lung sounds change in quantity, timing in relationship to

the respiratory cycle, and location after ETS?

3. What is the relationship between the change in quantity of adventitious

lung sounds recorded after suctioning and the volume and weight of

tracheobronchial secretions aspirated by ETS?

4. What relationship exists between the degree of importance of rhonchi

perceived by the patient's primary nurse, in the decision to suction, as

measured by the Decision To Suction Now (DSxN) instrument and the

quantity of rhonchi measured by TEWA prior to suctioning?

Data Collection

A convenience sample of 15 adult patients admitted to two critical care

units at one metropolitan teaching hospital were evaluated for participation in

this study. All 15 patients met the eligibility criteria, volunteered to participate

(or family consented), and had data collected at Time 1. Two subjects were lost

to attrition at Time 2, three at Time 3, and three at Time 4.

Data were collected on the lung sounds present before and after

suctioning. The decision to suction was made by the patient 's primary nurse.

Lung sounds were recorded using six analog microphones, an analog to digital

converter and a computer capable of storing the data in memory. The volume of

mucus removed by endotracheal suctioning was obtained and measured. The

criteria used by the nurse in the decision to suction the patient was measured

using a visual analog scale.

Data Analysis

Lung sounds were analyzed using computer based programs. The sounds were first listened to by the investigator. The sounds were then analyzed in the time and frequency modes. Based on these analyses, the sounds were categorized by type of adventitious sound, duration, timing in relation to the respiratory cycle and location over the chest. An expert in TEWA was available for consultation during data analysis.

The data for each category of lung sound was skewed and lack variability. As a result, the anticipated statistical analyses were not used. Instead, univariate descriptive statistics were used for question 1 and 2. To address question 3, the subjects were divided into groups that either had a specific lung sound or didn't. A Mann-Whitney U was used to determine if the groups differed on the volume of mucus aspirated. Question 4 was answered in a similar fashion. The subjects were divided into two groups. One group had rhonchi the other did not. The groups were compared for differences in the score of the rhonchi subscale of the DSxN using a Mann-Whitney U.

Summary of Findings

A recurrent pattern of lung sounds prior to suctioning was not identified. There were no similarities in lung sounds recorded in the same subject at different times. Although crackles, type I rhonchi and wheezes were encountered, they occurred less frequently than anticipated. Two sounds (type

II rhonchi and coarse sounds) that are not described by the ATS criteria were also recorded.

Coarse sounds were the only sounds that changed after suctioning. The duration of coarse sounds decreased after suctioning in most patients at Time 1 and 2. The source of coarse sounds is unknown. However, the waveform in the time mode is distinctive and easily recognized. There was a 35 percent reduction in the total occurrence of adventitious lung sounds after suctioning at Time 1 and 14% overall.

There was no difference in the amount of aspirate obtained from subjects grouped according to whether or not a specific sound was present. It is possible that the volume of aspirate was not a reliable indicator of airway clearance.

Finally, there was no difference in the perceived importance of rhonchi in the decision to suction in subjects with or without type I rhonchi recorded on TEWA. In addition, the DSxN was not predictive of the success of suctioning as measured by the volume of aspirate.

<u>Implications for Clinical Practice</u>

In this study the pattern of lung sounds using computerized techniques was examined to see if it compared with the volume of secretions produced on suctioning. The volume of secretions produced was chosen as an end point because it seemed logical. The purpose of suctioning is to remove secretions and suctioning "success" would seem intuitively to relate to the volume

produced. Furthermore the literature and common clinical opinion supports this belief.

The lung sound pattern did not correlate well with the volume of secretions. More importantly, the Decision to Suction Now instrument, the only available tool found in the literature, was also not predictive of the volume of secretions obtained. These surprising findings led to reexamining "volume of secretions" as an endpoint or gold standard.

Curiously, the volume of secretions produced appears to be most valuable when it is small (e.g. less than 1 cc) or zero. Such a result would indicate that either suctioning was not necessary or that the suctioning failed to remove the secretions. When amounts larger than one milliliter of secretions are suctioned there are other factors that need to be considered.

First, the suctioning procedure is blind. In other words, it is not known when secretions are obtained whether they are all or only a small portion of the total volume present. Even when a proportionally high volume is obtained, remaining secretions may still be causing abnormal sounds. Secondly, the suction catheter may not reach the area where secretions are present. For example, secretions may be present in the bronchus on the opposite side from the one that the suction catheter reaches, or the secretions may be further down the bronchus and out of reach of the catheter. Thirdly, the suction catheter may in fact loosen inspissated secretions which did not produce sound. These secretions may now be free to flap or move to sites where noise might be readily

generated. The suction catheter may cause bronchospasm and thus create conditions which favor the generation of wheezes.

For these reasons it is difficult to interpret the meaning of the lack of correlation of lung sounds with the volume of sputum produced on suctioning. More importantly these same objections apply to the use of sputum volume to any index employed to predict the appropriate timing and success of suctioning. Accordingly it is not surprising in retrospect that the Decision to Suction Now was also not predictive in this study (nor has is been proven in other studies either).

Indeed, review of the relevant literature reveals that adequate criteria for the timing of suctioning are not available at this time. The timing of suctioning remains an important problem because suctioning has adverse effects as previously mentioned (infection, hypoxemia, damage to airways). This procedure is also expensive, time consuming and often unpleasant to the patient. As mentioned the volume of secretions can be considered a reliable index when it is small (less than one milliliter). It was less than one milliliter in one third of the patients in this study. These results are similar to those obtained in the previous studies by Amborn (1976) and Knipper et al (1991). This means that a large number of people in this country get a costly, harmful, unpleasant procedure with little or no benefit.

<u>Implications for Future Research</u>

A logical conclusion from these observations and consideration is that additional work should be done to determine the most appropriate timing of suctioning patients with artificial airways. It is possible that the reasons for the failure of this study to show a correlation is that the number of subjects was too small or that the volume of secretions was too little to show an effect. Therefore it would be useful to study a larger population of subjects in several clinical locations. The design of the study should be changed to control for the effects of history (changes in clinical condition) on the production of secretions and generation of adventitious lung sounds. In addition, the effect of tidal volume on lung sounds should be addressed in subsequent studies. One possible solution is to standardize the tidal volume of all breaths recorded by using the manual control feature of the ventilator.

Computerized analysis of lung sounds remains a promising approach because: common clinical experience indicates that lung sounds are of value and even as this study was being done advances in methods to study sounds by computer are being made. Computerized lung sound analysis also makes it possible to study sounds at many sites over the chest at once and thus produce a map of their distribution on the surface of the chest. This is being further refined now that technology permits recording over 16 microphones at once. Lung sound mapping is a potentially important diagnostic tool. Lung sound researchers are using the differences in arrival times several microphones to localize the source of the sound within the chest. The localization of

intrathoracic sounds may be a particularly important technique for studying the correlation between airway secretions and lung sounds. Future research using localization techniques may be able to determine the anatomical location of a sound and whether or not suctioning would have an effect on a particular sound. Further, localization may make it possible to determine the location of the tip of the suction catheter. This is important both for research and practice considerations. Finally, further research is needed to describe the acoustic characteristics of the new waveform pattern identified in this study.

Chapter Summary

In summary, the patterns of lung sounds observed in this study did not predict the volume of secretions obtained with the exception that total numbers of lung sounds decrease after suctioning and coarse sounds decreased in duration. It was also surprising that the DSxN tool did not related to rhonchi recorded or predict the success of suctioning. This has implications for clinical practice, lung sound classification and future research.

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